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Exposure and Human Health Evaluation of Airborne Pollution from the World Trade Center Disaster

National Center for Environmental Assessment
Office of Research and Development
U.S. Environmental Protection Agency
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List of Acronyms and Abbreviations

ACGIH	American Conference of Governmental Industrial Hygienists
ACM	asbestos-containing materials
ADD	Average Daily Dose
AHERA	Asbestos Hazard Emergency Response Act
AIRS	Aerometric Information Retrieval System
AQI	Air Quality Index
As	arsenic
ATSDR	Agency for Toxic Substances and Disease Registry
Br	bromine
Ca	calcium
cc	cubic centimeters
Cd	cadmium
CDC	Centers for Disease Control and Prevention
Cl	chlorine
CO	carbon monoxide
Cr	chromium
Cu	copper
DL	detection limit
DOE	Department of Energy
EOHSI	Environmental and Occupational Health and Safety Institute
EPA	Environmental Protection Agency
EPA ERT	Environmental Protection Agency Environmental Response Team
EPA-STSC	Environmental Protection Agency Superfund Toxics Support Center
ESD	Environmental Services Division, of EPA's Region 7 Office in Kansas City
f	fibers of asbestos
FDNY	Fire Department of New York
FEMA	Federal Emergency Management Agency
GFF	glass fiber filter
HEAS	Human Exposure and Atmospheric Sciences Division, in EPA's NERL
IBB	increment in body burden
K	potassium
kg	kilogram
LADD	lifetime average daily dose
LOC	level of concern
LW	lipid weight
MCL	Maximum Contaminant Level
µg	microgram
µm	micrometer
MOE	Margin of Exposure
MRL	Minimum Risk Level
NAAQS	National Ambient Air Quality Standard
NCEA	National Center for Environmental Assessment, of EPA's Office of Research and Development

ND	Non-detect
NERL	National Exposure Research Lab of EPA's Office of Research and Development
ng	nanogram
NHEERL	National Health and Environmental Exposure and Risk Laboratory, of EPA's Office of Research and Development
NIEHS	National Institute of Environmental Health and Safety
NIOSH	National Institute for Occupational Safety and Health
NO_2	nitrogen dioxide
NOAEL	no-observed-adverse-effect level
NY	New York
NYC	New York City
NYCDEP	New York City Department of Environmental Protection
NYCDOHMH	New York City Department of Health and Mental Hygiene
NYSDOH	New York State Department of Health
NYSDEC	New York State Department of Environmental Conservation
ORD	EPA's Office of Research and Development
OSHA	Occupational Safety and Health Administration
PAH	polycyclic aromatic hydrocarbons
Pb	lead
PCB	polychlorinated biphenyl compounds
PCM	phase contrast light microscopy
Pd	palladium
PEL	Permissible Exposure Limit
pg	picogram
PM, $PM_{2.5}$, PM_{10}	Particulate matter, and PM at less than 2.5 μm and less than 10 μm diameter
ppb	part per billion
ppm	part per million
PS	public school
PUF	polyurethane foam plug for air monitoring
REL	Recommended Exposure Levels
RfC	Reference Concentration
S	sulfur, or structures of asbestos
Sb	antimony
SF	cancer slope factor
Si	silica
SO_2	sulfur dioxide
SRIXE	synchrotron radiation-induced X-ray emission
STEL	Short Term Exposure Level
STSC	Superfund Technical Support Center
TEF	toxicity equivalency factor
TEM	transmission electronic microscopy
TEOM	tapered element oscillating microbalance
TEQ	toxic equivalent concentration
TLV	Threshold Limit Value

TWA	time-weighted average
UR	unit risk, for estimating cancer risk due to inhalation
USGS	United States Geological Survey
VAPS	versatile air pollutant sampler
VOC	Volatile organic compound
WTC	World Trade Center
XRF	x-ray flourescent
Zn	zinc

FOREWORD

The National Center for Environmental Assessment (NCEA), a major component of the Office of Research and Development (ORD), is EPA's national resource center for human health and ecological risk assessment. NCEA conducts risk assessments, carries out research to improve the state-of-the-science of risk assessment, and provides guidance and support to risk assessors.

Following the collapse of the World Trade Center towers on September 11, 2001, New York State and Federal agencies initiated numerous air monitoring activities to better understand the ongoing impact of emissions from the disaster. This report focuses on these air measurement data, evaluating them in terms of what is typical for New York City or general urban background and interpreting it with regard to the potential for human health consequences. The report does not evaluate exposures possibly faced by rescue or clean-up workers and briefly discusses past and current indoor monitoring efforts.

The analysis in this report supports three general findings: 1) Persons exposed to the extremely high levels of ambient particulate matter and its components during the collapse of the World Trade Center towers and for several hours afterwards were likely to be at risk for immediate acute (and possibly chronic) respiratory and other types (e.g., cardiovascular) of symptoms. 2) The first measurements of some of the contaminants were on September 14, while other contaminants were not measured until September 23. Available data suggest that the concentrations within and near Ground Zero were likely to be highest in the few days following September 11. Because there are only limited data on these critical few days, exposures and potential health impacts cannot be evaluated with certainty for this time period. 3) Except for exposures on September 11 and possibly during the next few days, persons in the surrounding community were unlikely to suffer short-term or long-term adverse health effects caused by exposure to elevations in ambient air concentrations of the contaminants evaluated in this report. These elevated concentrations were measured mostly within and near Ground Zero, and they lasted for one to three months after September 11. The monitoring data indicate that air concentrations decreased to background levels that are characteristic of pre-September 11 levels in the New York City metropolitan area by around January or February of 2002.

Ultimately, it will be difficult to ascertain with certainty what effects resulted when people were surrounded by initial clouds of dust, or were subsequently exposed to the elevated concentrations that are discussed in this report. Epidemiologic studies of the exposed populations that are being conducted by various agencies and institutions should provide a more scientifically robust evaluation for future evaluations of health effects.

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Executive Summary

In the days following the September 11, 2001, terrorist attack on New York City's World Trade Center (WTC) towers, many federal agencies, including the United States Environmental Protection Agency (EPA), were called upon to bring their technical and scientific expertise to the national emergency. EPA, other federal agencies, and New York City and New York State public health and environmental authorities initiated numerous air monitoring activities to better understand the ongoing impact of emissions from that disaster. These efforts generated an immense amount of data. Many EPA offices and programs quickly became involved with these activities, providing scientific, engineering, public health, and management expertise to help cope with the after effects of the collapse of the WTC towers. EPA Region 2, which includes the New York City metropolitan area in New York and New Jersey, is the Agency's lead office on these activities, including the important and complicated task of community outreach and communication. As part of these activities, Region 2 requested that EPA's Office of Research and Development (ORD) conduct a human health evaluation of exposure to air pollutants resulting from the WTC disaster.

The evaluation in this report relies primarily on the analyses of ambient air samples from monitors located at the perimeter of the WTC Ground Zero and at various other sites in lower Manhattan and surrounding areas. It is an assessment of the inhalation exposure and potential human health risk incurred by the general population residing and working in the vicinity of the WTC. Numerous other efforts have been conducted or are ongoing that address other aspects of exposure and potential risk associated with the collapse of the WTC towers, including:

1) Ground Zero worker exposures: This report reviews some of the data collected by the Occupational Safety and Health Administration (OSHA) and the National Institute of Occupational Safety and Health (NIOSH) that address the exposures faced by fireman and rescue workers, but does not explicitly evaluate these exposures.

2) Indoor exposures: Similarly, this report reviews some of the data collected on indoor air and dust, particularly a recently completed study by the New York City of Department of Health and Mental Hygiene (NYCDOHMH) and the Agency for Toxic Substances and Disease Control (ATSDR). It also provides an overview of the ongoing efforts by EPA Region 2 to clean apartments and evaluate the quality of indoor air and dust. Future reports by EPA Region 2 will detail these efforts and monitoring results.

3) Epidemiology studies: Chapter 7 of this report provides an overview of the types of studies that are ongoing which will evaluate health impacts experienced by workers and others known to be in the vicinity of WTC in the days and weeks following September 11, 2001. These studies are being conducted and sponsored by the National Institute of Environmental Health Studies (NIEHS), and others.

The ambient air monitoring activities described in this report were undertaken by federal, state and local agencies which have made their analytical results available to EPA for analysis. Most of the monitors were placed following the disaster, with the intent of characterizing outdoor levels of WTC-generated air pollutants at locations surrounding the WTC site at

different distances. Some monitors for particulate matter (PM), operated by New York State, existed prior to the disaster.

This report focuses on: *PM, metals (lead, chromium and nickel compounds), polychlorinated biphenyls (PCBs), dioxin-like compounds, asbestos, and volatile organic compounds (VOCs).* These substances are included because monitoring indicated that they correlated with the disaster site in both time and space, and because they pose a potential concern for health impacts. PM was generated by the collapse of the WTC buildings, the recovery and demolition operations, and the lingering fire. Lead and asbestos were believed to be components of the WTC building materials. PCBs were used as dielectric fluid in transformers and capacitors. Dioxin and VOCs are produced as a result of combustion and volatilization from fuels. The assessment is limited to an evaluation mainly of the inhalation of airborne contaminants, although dust ingestion and dermal contact may also have led to exposures within and near Ground Zero.

Elevated concentrations of these contaminants were found within and near Ground Zero for a short period of time after September 11. "Elevated" is used in this discussion to denote concentrations of a contaminant that were significantly higher, by a factor of 10 or more and often by factors of 100 or 1000, compared to other measurements of the contaminant taken in the WTC monitoring program or compared to concentrations that are typically found in New York City or in general United States urban settings. Many of these elevated measurements were identified as having occurred in "restricted zones," that is, zones where access was limited to emergency management and rescue personnel and to other credentialed people. In general, the monitoring data, even within Ground Zero, indicate that ambient air levels for all of these substances decreased to background ambient concentrations that are characteristic of pre-September 11 levels in the New York City metropolitan area by around January or February of 2002.

The analysis in this report finds that:

- ***Persons exposed to the extremely high levels of ambient particulate matter and its components during the collapse of the World Trade Center towers and for several hours afterwards were at risk for immediate acute (and possibly chronic) respiratory and other types (e.g., cardiovascular) of symptoms.***

- ***The first measurements of some of the contaminants were on September 14, while other contaminants were not measured until September 23. Available data suggests that the concentrations within and near Ground Zero were likely to be highest in the few days following September 11. Because there are only limited data on these critical few days, exposures and potential health impacts cannot be evaluated with certainty for this time period.***

- ***Except for exposures on September 11 and possibly during the next few days, persons in the surrounding community were unlikely to suffer short-term or long-term adverse health effects caused by exposure to elevations in ambient air concentrations of the contaminants evaluated in this report. These elevated concentrations were***

measured mostly within and very near Ground Zero, and they lasted for 1 to 3 months after September 11.

While the conclusions reached in this report represent the current scientific understanding of the toxicity that these contaminants pose to people, combined with EPA's evaluation of exposure to these contaminants based on available air monitoring data, it cannot be stated with certainty what effects resulted when people were engulfed in the initial cloud of dust or were subsequently exposed to the elevated concentrations that were found. Epidemiologic studies of the exposed populations that are currently being conducted by various agencies and institutions should provide a more scientifically robust evaluation for future evaluations of health effects.

The risk evaluation approach taken in most instances was to compare the measured air levels at locations near Ground Zero to established health benchmarks for inhalation exposure and to typical urban background levels. OSHA Permissible Exposure Levels (PELs), NIOSH Recommended Exposure Levels (RELs), and Agency for Toxic Substances and Disease Registry (ATSDR) Minimum Risk Levels (MRLs) were among the benchmarks included in this evaluation. Where available, benchmarks established to protect against acute and subchronic exposures were used. Benchmarks that are intended to protect against exposures lasting over one year or throughout a lifetime, like the EPA Reference Concentration (RfC), were only used if other more appropriate benchmark values were not available.

A simple comparison of air measurements to health benchmarks or to typical background levels can be thought of as a "screening" exercise; the purpose of the exercise is to identify possible problems. If the majority of samples are much less than a benchmark, in most cases it would be appropriate to conclude that a health impact is unlikely. Similarly, if most air measurements are similar to typical background levels, then it can be concluded that emissions from the WTC are not impacting air or influencing exposure and health. On the other hand, if most samples exceed a benchmark, then it may be appropriate to consider the possibility that a health impact may have occurred, or could occur, depending on the circumstances.

Efforts will continue at EPA to further characterize exposures and health impacts that resulted from the collapse of the WTC Towers, and to build on the risk evaluation presented in this report. Some additional future considerations could include: evaluating other contaminants that were measured, evaluating the indoor environment in more depth, evaluating other pathways of exposure and other exposure media such as dermal contact to contaminated dust, investigating the combined effects of exposure to more than one contaminant, conducting further toxicity testing with laboratory animals, and considering results from ongoing epidemiological studies.

Summaries of the findings for each contaminant/class of contaminants are presented below:

Particulate Matter. *People caught in the initial dust/smoke cloud that encompassed lower Manhattan after the collapse of the WTC buildings on September 11 were briefly exposed (4 - 8 hours) to quite high levels (in the milligrams per cubic meter, mg/m^3, range) of airborne particulate matter (PM). Also, during the first several days after the disaster, PM levels in the air at the WTC perimeter exceeded EPA's daily $PM_{2.5}$ NAAQS (65 µg/m^3, 24-hr); and $PM_{2.5}$*

concentrations at some other nearby lower Manhattan sites exceeded EPA's 40 micrograms per cubic meter ($\mu g/m^3$) 24-hour Air Quality Index (AQI) level of concern for susceptible subgroups. The high PM concentrations recorded very near WTC Ground Zero during late September and early October may imply increased chronic health risks for the most highly exposed individuals (e.g., persons spending extended periods of time within the WTC work zone without wearing protective respirators). By mid- to late October, PM values across lower Manhattan had largely returned to levels typical of New York City and other US urban areas, with only a few WTC or nearby sites occasionally approaching or exceeding the AQI level of concern.

Many individuals were exposed for a few hours to very high PM concentrations in the initial dust cloud that spread over lower Manhattan on September 11. Also, high levels of airborne particles were detected during the first several days after September 11 at a few already existing PM monitoring sites scattered across the New York City area. Hourly or daily fine particle (less than 2.5 μm in diameter, $PM_{2.5}$) values at some new sites set up by EPA or New York State exceeded 40 $\mu g/m^3$ (though the AQI applies only to the daily averages).

$PM_{2.5}$ measurements from newly established monitoring sites around the WTC perimeter varied widely, depending on wind direction. Daily average (24-hr) $PM_{2.5}$ concentrations on some days exceeded 200 $\mu g/m^3$ at one WTC perimeter site or another during late September and early October. However, $PM_{2.5}$ concentrations decreased rapidly with distance from the WTC, with few $PM_{2.5}$ values exceeding the 40 $\mu g/m^3$ AQI at monitoring locations ranging from 3 to 10 blocks away from the WTC. During the entire period following September 11, $PM_{2.5}$ values recorded at lower Manhattan sites away from the WTC perimeter were not markedly different than during periods before or since, as the New York metropolitan area routinely experiences $PM_{2.5}$ values near and above the AQI.

Concentrations of various elements (e.g., calcium, sulfur, silicon, lead, and other metals) in WTC $PM_{2.5}$ particles also were enriched above typical background levels on an episodic basis at sites mainly on or near the WTC perimeter, including on some days extending into late October and into November.

The issue of alkalinity of WTC dust and its potential as a possible health concern for exposed individuals is raised by observations by the United States Geological Survey (USGS) and academic researchers of high pH (> 11.0) of aqueous solutions of settled WTC dust not leached by rainfall. After late September, indoor exposures to such dust probably warrant more concern than outdoor exposures for possible acute irritative effects or more chronic health effects, not only because of the basic nature of some constituent particles but also because of other unusual features, such as slender microscopic glass fibers with toxic materials attached to them or very fine particles composed of unusual combinations of silica coalesced with lead or other toxic materials.

Metals

Lead. *Persons caught in the initial WTC-related dust cloud experienced brief exposures to high levels of lead (Pb), based on analyses of deposited dust samples. In late September 2001, air lead concentrations at the WTC perimeter sites reached levels above 1.5 μg/m³ on some days. However, the air lead levels averaged over 90 days (late September - late November) did not exceed the EPA National Ambient Air Quality Standard (NAAQS) of 1.5 μg/m³ averaged over a 90-day period. After mid-October, air lead at all sites in lower Manhattan outside WTC Ground Zero dropped to levels more comparable with background concentrations typical of NYC and other northeastern United States urban areas. On the basis of ambient air and dust data, there is little indication of any substantial health risks being associated with lead exposures of the general population in lower Manhattan areas around the WTC site.*

On several days in late September 2001, 24-hour Pb concentrations at the WTC Ground Zero perimeter sites exceeded 1.5 μg/m³. This level was again approached or exceeded at one or another WTC perimeter site during early October (10/3 -10/5). However, airborne Pb rapidly decreased with distance from the WTC perimeter sites, with Pb concentrations on the same days when Pb levels were elevated at Ground Zero being substantially lower at several locations within 3-10 blocks from the WTC (i.e., mostly within the 0.11 to 0.63 μg/m³ range of 24-hour Pb levels observed at some Manhattan and Brooklyn sites during the 1990's). After mid-October, 2001 Pb readings for all WTC perimeter sites and other lower Manhattan sites remained below 1.5 μg/m³, with few even exceeding 0.5 μg/m³.

Lead concentrations in bulk dust samples taken close to the WTC within days after September 11 ranged up to 625 μg/g (ppm). This level is well below street dust Pb levels on or near heavily traveled roadways prior to phase-down of Pb in gasoline in the late 1970's, which often were well in excess of 1000 - 2000 ppm, and it compares well with the 500 - 1000 ppm street dust or soil lead levels found in northeastern or midwestern U.S. urban areas well into the 1990s.

In general, the observed ambient air lead levels did not appear to pose increased health risks for the general public. However, susceptible persons (especially any pregnant women) who may have experienced extended exposures to elevated Pb levels within WTC Ground Zero work areas while not wearing appropriate respiratory protective gear or who were exposed to indoor WTC-derived dusts with high Pb loadings could possibly be at increased risk for chronic health effects. Evaluation of blood lead levels and pertinent medical records for any pregnant women exposed at Ground Zero or in its immediate vicinity during late September/early October could provide useful further data by which to assess any such possible health risks associated with WTC-generated lead emissions.

Chromium. *Samples evaluated for total chromium at Ground Zero and at sites surrounding Ground Zero never exceeded the OSHA PEL of 1 mg/m³ or the ATSDR Intermediate Minimum Risk Level (MRL) for chromium VI particulates of 1.0 μg/m³. On the basis of the samples evaluated, exposures to chromium were not likely to cause any adverse health effects.*

All 21 Ground Zero air samples evaluated for total chromium were collected at Building 5 between September 23 and January 31. Additionally, approximately 512 air samples collected at sites surrounding Ground Zero were evaluated for chromium, including 86 samples collected at landfills and 16 samples from personal air monitors worn by New York City fire department personnel. No exceedences of the OSHA PEL or the ATSDR Intermediate MRL for chromiumVI particulates were detected. However, it was noted that concentrations in the range of 0.20 and 0.40 $\mu g/m^3$ were measured for about a month month after September 11, to then drop to more typical urban backgrounds less than 0.10 $\mu g/m^3$

Nickel. *Nickel samples evaluated at Ground Zero and at sites surrounding Ground Zero never exceeded the OSHA PEL of 1 mg/m^3. On the basis of samples evaluated, exposures to nickel were not likely to cause any adverse health effects.*

All 21 Ground Zero air samples evaluated for nickel were collected at Building 5 between September 23 and January 31. Additionally, approximately 637 air samples collected at sites surrounding Ground Zero were evaluated for nickel, including 86 samples collected at landfills. No exceedences of the OSHA PEL were detected. Furthermore, and unlike chromium and other contaminants, all measurements from September 11 on at all sites were at background levels.

Polychlorinated Biphenyls. *Of the several hundred polychlorinated biphenyl (PCB) air measurements available, only one sample was elevated above 100 nanograms total PCB per cubic meter (ng/m^3), at 153 ng total PCB/m^3, and only three samples were above 50 ng total PCB/m^3. This compares to typical urban background PCB concentrations in the range of 1 - 8 ng total PCB/m^3. After a month, nearly all readings were in the range of typical urban PCB concentrations or were not detected. There were no exceedences of any short-term occupational health benchmark, including the NIOSH REL of $1*10^3$ ng/m^3 or the OSHA PEL of $5*10^3$ ng/m^3. It is concluded that exposures were of minimal concern for cancer risk.*

Several hundred PCB air measurements were obtained at a total of 12 locations in the vicinity of Ground Zero from September 16, 2001, through April 24, 2002. The highest PCB air concentration measured was 153 ng PCB/m^3, and this occurred on October 2, 2001, at the Ground Zero site, WTC Building 5 SW. Typical urban air concentrations of PCBs are in the range of 1 - 8 ng/m^3. The source of these elevated PCB air measurements is speculated to be the smoke emanating from the smoldering fires at Ground Zero. PCBs were entrained in the smoke as a consequence of PCB-containing materials in the WTC buildings. After November 3, 2001, all of the PCB monitoring sites showed results consistent with PCB levels in air that are typical of urban areas of the U.S. A simple screening exercise showed that an incremental lifetime cancer risk due to exposure to short-term elevation of PCBs would be in the range of 10^{-8} or lower, which is judged to be of minimal concern. With respect to non-cancer effects, all PCB air measurements are several orders of magnitude below No Observed Effect Levels (NOELs) in experimental animal studies. In addition, levels of PCBs observed near or at the WTC site are below the NIOSH REL of $1*10^3$ ng/m^3 (NIOSH, 2002), and several

orders of magnitude below the OSHA PEL of $5*10^5$ ng/m^3. The NIOSH REL is an 8-hr time-weighted average air concentration. It is associated with long-term or repeated exposures, and is protective of effects on the liver and the reproductive system. The OSHA PEL is also an 8-hr time-weighted average air concentration. It is associated with long-term or repeated exposures and is protective of effects on the ski (dermatitis).

Dioxins. *Monitoring data indicate that dioxin toxic equivalent (TEQ) levels in air near the WTC were up to three orders of magnitude higher (1000 times higher) than is typical for urban areas in the United States. Typical levels for urban areas are 0.1 to 0.2 picograms of TEQ per cubic meter (pg TEQ/m^3), while levels found in Ground Zero and near Ground Zero, starting September 23 (the date of the first sample taken) and continuing through late November ranged from 10 to over 150 pg TEQ/m^3. Concentrations measured several blocks from Ground Zero were still elevated above typical urban background, but considerably lower than sites in or near ground zero, ranging from 1 to 10 pg TEQ/m^3 during this same time period. Everywhere these elevations dropped rapidly, and the data suggest that by December 2001, levels decreased to background levels. These levels need to be considered in the context of total exposure to dioxin, 95% of which is attributed to dietary intake in normal background settings. Therefore, although inhalation exposure to dioxin at these elevated air concentrations is significantly higher than typical inhalation exposure to dioxin, an individual's overall exposure to dioxin may not be impacted significantly. An exposure and risk screening exercise was conducted with available monitoring data, and the results suggest that these elevations did not result in a significant elevation in cancer or non-cancer risk over the background risk for exposure to dioxin-like compounds.*

The monitoring data indicate that, through late November, dioxin TEQ levels in air near the WTC were distinctly elevated compared with typical levels in urban air. An exposure and risk screening exercise based on these high concentrations suggest a temporary elevation in exposures for Ground Zero workers but very minimal impact for nearby residents and office workers. It is concluded that these potential exposures during 2001 do not constitute a public health concern. Dietary intake of dioxins is much higher than inhalation intake, and thus, the ambient concentrations of dioxin within and near Ground Zero, although considerably elevated above typical urban air concentrations of dioxin, are not as significant as suggested by the orders of magnitude in elevation indicated above.

However, much of the data obtained from within and near the WTC site are of limited interpretive value due to high detection limits. When dioxin-like compounds were not detected in an air sample, the TEQ concentration was determined by assuming that each dioxin-like compound was present in the air at one-half the detection limit for that compound. This is typical for calculating dioxin TEQ concentrations, and for other contaminants as well. Because dioxin-like compound concentrations were considerably elevated in the ambient air from September through late November 2001 within and near Ground Zero, these concentrations were able to be measured, despite high detection limits. Concentrations ranged from 10 to 150 pg TEQ/m^3 during this time, which was between 100 and over 1500 times higher than typically found in urban air.

The reported TEQ concentrations that were compromised due to high detection limits ranged in value from 0.5 to 5.0 pg TEQ/m^3, which is about 5 to 50 times higher than normal urban background air concentrations. These measurements came from 9 specific air samplers which were located within Ground Zero (1 sampler) and near the WTC site (8 samplers). In general, the dioxin method's detection limit is calculated by dividing the lowest mass of dioxin that the method can detect by the air that contained that amount, namely the air that flowed through the sampler. Thus, as more air is drawn through the sampler, the detection limit is lowered. These 9 air samplers operated for 8-hour periods, and drew in about 7 m^3 of air. They began operation on September 23, 2001.

Three other air samplers were operated for 72-hour periods, and drew in about 1000 m^3 of air. These monitors were located several blocks from the perimeter of Ground Zero, and began operation on October 12. Because much more air was drawn into these samplers, the detection limits obtained for the dioxin-like compounds were lower, and TEQ concentrations could be routinely quantified as levels less than 1.0 pg TEQ/m^3. The first sampling events in October through November in these three monitors resulted in concentrations that were still elevated above typical background TEQ concentrations, at between 1 and 10 pg TEQ/m^3. Starting at the beginning of December, 2001, and continuing through the termination of sampling in May of 2002, the measurements in these samplers decreased to levels that were mostly less than 0.10 pg TEQ/m^3. More detail on these two sets of monitors (the 9 monitors sampling for 8 hours, and the 3 monitors sampling for 72 hours) is provided in Section IV.d below.

All the reported TEQ measurements from these 9 monitors for 2002, and the measurements from them in upwind conditions during 2001 (i.e., when the plume was moving in a direction opposite the monitors), were in this one-half detection limit range of 0.5 to 5.0 pg TEQ/m^3. Thus, the ability to assess exposure during the early months of 2002, where there may have been elevations near Ground Zero as a result of cleanup activities, was compromised. Because the health risk from dioxin exposure is associated with accumulation of residues in body tissues, continued dioxin TEQ exposure within and near Ground Zero throughout 2002 could not be evaluated. The risk screening exercises conducted for dioxin were limited to the time period when the concentrations were highest and dioxin was detected. This issue is described in more detail in Section IV.d.

Asbestos: *The large majority of outside air measurements of asbestos were below established benchmarks and within the range of typical background levels. However, and similar to other contaminants, the few exceedences that were measured occurred near September 11 in time and close in proximity to the WTC. Limited available evidence suggest the incursion of asbestos to the indoor environment. A small study which sampled the indoor environment of two apartments on September 18 showed very high indoor levels of asbestos. A larger and more systematic study which sampled in November and December of 2001 suggested that indoor levels of asbestos in dust were slightly higher near the WTC as compared to indoor levels in dust further away. Current efforts by the EPA focus on the measurement and clean-up of residential apartments near the WTC.*

A total of 12,676 ambient samples in lower Manhattan were measured by phase contrast light microscopy (PCM, used to identify structures greater than 5 μm in length), and 8,872 of these were also measured by transmission electronic microscopy (TEM; used to identify structures less than 0.5 μm in length). Only 23 samples were found to exceed the Asbestos Hazard Emergency Response Act (AHERA, which uses the TEM measurement technique) abatement standard of 70 structures per square millimeter (S/mm^2), and there were no exceedences of the OSHA PEL (which uses the PCM measurement technique) of 0.1 fiber per cubic centimeter (f/cc). Most of the exceedences of the AHERA standard occurred during September 2001 adjacent to Ground Zero in "restricted zones". The highest concentrations of PCM-measured fibers in ambient air were recorded during the 30 days following September 11, 2001, at sites in the vicinity of the WTC. Concentrations during this time were in the range of 0.04 to 0.08 f/cc. There has been a steady decline in the asbestos levels through the first few months of 2002, to correspond to a steady background state of ND to <20 S/mm^2 as measured by TEM and in the range of 0.003 f/cc as measured by PCM, a level which is typical for urban background.

A slightly higher occurrence rate of AHERA exceedences occurred within the exclusion zone at the Staten Island Landfill; 51 out of 5,207 samples taken. Most of the exceedences occurred during October and November 2001, corresponding to the time that most of the debris was being unloaded. Only one sample in Queens was above 70 S/mm^2, whereas no exceedences were observed in the other boroughs of NYC or in New Jersey.

The highest measurements of asbestos available for evaluation in this report were taken within two apartments sampled on September 18, 2001. One apartment was highly affected by the collapse of the WTC towers with completely shattered windows and dust piled throughout the apartment. The other was in a building that had little exterior damage, but had visible dust on surfaces within the building and in the apartment sampled. In the severely damaged apartment, five air measurements of asbestos ranged from 6277 to 10,620 S/mm^2 using the AHERA protocol. One sample taken just outside on a window ledge of this apartment measured 548 S/mm^2. However, it is likely this high reading was influenced by the air quality on the inside of the apartment, which showed exceedingly high asbestos concentrations, and was likely not representative of outdoor concentrations. The six indoor samples in the less impacted apartment exceeded the 70 S/mm^2 AHERA standard at levels ranging from 141 to 379 S/mm^2. A rooftop sample at this location was low at 6.5 S/mm^2.

A systematic study of residential apartments by the NYCDOHMH and the ATSDR showed very little impact to residential apartments compared with this September 18 study, but still a difference between apartments in lower Manhattan and comparison apartments. From November 4 through December 11, 2001, environmental samples were collected in and around 30 residential buildings in lower Manhattan. In addition, four buildings above 59th Street were sampled and used as a comparison area for this investigation. Importantly, asbestos was not detected above background levels in air samples in all apartments sampled (with background defined as 0.003 f/cc, a level which is typical for urban background). Bulk dust samples were collected both indoors and on

outdoor surfaces and analyzed for the presence of asbestos by both PLM (polarized light microscopy) and TEM. Asbestos was detected in settled indoor dust in 10 of 57 (16%) lower Manhattan residential units sampled, with the positive samples showing a maximum of 1.5% asbestos in dust. By comparison, no asbestos was detectable in dust samples collected in the 5 comparison residences. In outdoor dust collected at lower Manhattan properties, asbestos was detected in 6 of 14 (43%) samples, with a maximum asbestos concentration in dust of 3.4%.

Volatile Organic Compounds. *The Ground Zero samples of volatile organic compounds (VOCs) were generally not taken in the breathing zone of workers and were not representative of the general air quality at the site. Most of the data were collected within plumes from fires and smoldering rubble to alert the Fire Department of New York (FDNY) and the contractors/union health/safety officers working at Ground Zero about conditions that posed immediate health concern to the workers and, as such, were more representative of emissions rather than exposures. For this reason, an analysis of Ground Zero worker exposures for VOCs was not conducted. However, eleven VOCs were evaluated at sites surrounding Ground Zero. No exceedences of screening benchmarks were seen for 1,4-dioxane, ethanol, styrene, tetrahydrofuran, and xylenes. Exceedences of screening benchmarks were seen for acetone, benzene, 1,3-butadiene, chloromethane, ethylbenzene, and toluene. Except for benzene, exceedences for these chemicals occurred in restricted zones. Also, the exceedences were all grab samples. Twenty-four hour samples of benzene, 1,3-butadiene, ethylbenzene, and toluene all were about three orders of magnitude (1000 times) lower than the grab samples, demonstrating the difference between 4-minute grab samples taken within plumes and day-long averages. The exceedences for benzene were more frequent, some were further from Ground Zero than the other VOCs, and the 24-hour samples were lower but within a factor of 10 of the grab sample exceedences. This suggests that elevated concentrations of benzene (above typical background by about a factor of 10) may have been sustained for a month or more after September 11.*

On the basis of available monitoring data, it is concluded that the exceedences of the screening benchmarks in restricted zones for acetone, 1,3-butadiene, chloromethane, ethylbenzene, and toluene do not represent a public health risk to persons living or working at sites surrounding Ground Zero.

The data for benzene were not as definitive. Because the 24-hour samples were measured at levels that were closer in magnitude to the grab sample exceedences than the other VOCs, within a factor of 10, this would suggest that the grab sample concentrations were closer to sustained concentrations rather than short-term plume concentrations only. Also, these 24-hour concentrations were near the ATSDR Intermediate MRL of 0.004 ppm and higher than the historical average for New York City of about 0.0005 ppm. The data suggest that the possible exposures to benzene at levels that approach the MRL did not last longer than 45 days. Whether or not specific health effects occurred due to exposure to benzene is unknown, but given that the exceedences and elevations above typical background were near Ground Zero and mostly within restricted zones, the data suggests that the exposures to the general population were of minimal concern.

Air Concentrations During the First Several Days After September 11: An event such as September 11 demonstrates that the greatest environmental impacts occur in the first 24 to 48 hours and in areas close to the site. Difficulties associated with site access and security, power supply sources, equipment availability and analytical capacity hindered efforts by EPA and the New York State Department of Environmental Conservation (NYSDEC) to put air monitors in place immediately after the attack. While dust samples were collected for analysis on September 11, the first air samples of some of the critical contaminants were not taken until September 14, such as asbestos, while other contaminants were not sampled until September 23, such as dioxin. Rapid initiation of monitoring will allow the measurement of air concentrations that can be very important for evaluation of inhalation exposures and potential short and long-term human health impacts. An examination of the concentrations measured during September show that the highest concentrations were the ones taken closest in time to September 11, closest in proximity to Ground Zero, and in the downwind direction. For example, five measurements of dioxin TEQs were over 100 pg TEQ/m^3 (all others were under 100 pg TEQ/m^3), and these were the first measurements in the three nearest downwind monitors: the first 3 measurements in the WTC Building 5 monitor on September 23 (160 pg TEQ/m^3), October 2 (170 pg TEQ/m^3), and October 4 (170 pg TEQ/m^3), the first measurement at the Church and Dey monitor on September 23 (130 pg TEQ/m^3), and the first measurement at the Liberty and Broadway monitor on September 23 (100 pg TEQ/m^3). While the highest dioxin measurements were found on September within and to the east of Ground Zero, three samplers to the west of Ground Zero showed background levels of dioxins on September 23. Similar trends were seen for other contaminants. It is reasonable to conclude that air concentrations within and very near Ground Zero would have been at least at these high levels and probably higher during the first several days after September 11. These areas were in restricted zones, which minimized overall exposures, and exposures were further minimized for individuals who used protective gear and clothing.

Occupational and Indoor Exposures: Extensive data sets are available from OSHA and NIOSH on occupational exposures on the Ground Zero site. Many of these samples were personal air monitors, and as such, are the most appropriate types of samples for evaluating inhalation exposures of workers. The contaminants evaluated in this report and many more are included in these data sets. The vast majority of samples in both data sets were below occupational standards including OSHA PELs and NIOSH RELs. The ATSDR has completed a study of residential apartments (NYCDOHMH/ATSDR, 2002). Testing occurred between November 4 and December 11, and included 57 apartments in lower Manhattan as well as 5 comparison apartments. In all tested apartments (lower Manhattan and comparison), airborne fibers were not detected above background levels in any of the indoor air samples. However, bulk dust samples showed asbestos in 16% of the apartments in Lower Manhattan, and none in the comparison apartments. Also, synthetic vitreous fibers (SVF or fibrous glass) were found in both indoor and outdoor samples in Lower Manhattan. Another study sampling indoor air and dust on September 18 in 2 locations very near Ground Zero found significantly high concentrations of asbestos in both air and dust, but low, background, concentrations of dioxin, PCBs and metals.

Exposure and Human Health Evaluation of Airborne Pollution from the World Trade Center Disaster

Section I. Overall Purpose and Scope of Assessment

The purpose of this document is to provide a preliminary assessment of the potential human health impacts associated with exposures to emissions caused by the September 11, 2001, collapse of the World Trade Center (WTC) towers. This assessment focuses on a disaster that has already occurred, and it became a challenge to evaluate the seriousness of health impacts that may have resulted (or may still result) from past exposures to contaminants. This situation presents problems that are different from those faced in analyses to support the proactive establishment of environmental standards, to determine emission limits from air sources, and in similar regulatory venues where risk assessment procedures are used. In such circumstances, risk managers can make an active choice regarding the level of protection that is to be achieved and how uncertainties will be weighed in that process. In addressing exposures resulting from the WTC attack, those options are not available. Accordingly, this report attempts to take a practical, integrative approach to evaluating and conveying the potential impacts and their seriousness from a public health perspective.

Six contaminants/contaminant classes were evaluated in this assessment. These included: particulate matter (PM), metals (lead, chromium, and nickel), polychlorinated biphenyls (PCBs), dioxins, volatile organic compounds (VOCs; benzene and several others), and asbestos. Although hundreds of different substances have been measured in various media, these substances were selected for evaluation because monitoring indicates that they correlate with the disaster site in both time and space, and because they pose a potential concern for health impacts. PM was generated by the collapse of the WTC buildings, the recovery and demolition operations, and the lingering fire. Lead and asbestos were believed to be components of the WTC building materials. PCBs were likely used as dielectric fluid in transformers and capacitors. Dioxin and VOCs are produced as a result of combustion and volatilization from fuels. A screening of all substances was not possible in the time available. Instead, a judgement was made that the above listed chemicals might pose the greatest health concerns. Other contaminants may be evaluated in later reports.

Potentially exposed populations could include anyone who lives or works in the vicinity of WTC, such as cleanup workers, office workers, merchants, or residents. Available data were not always sufficient to evaluate the potential impacts to all populations from all contaminants. For example, it was decided that monitoring data for VOCs at Ground Zero could not be used to evaluate VOC exposure to Ground Zero workers. The reasons for this are twofold. First, most of the EPA data for VOCs at Ground Zero came from simple grab samples taken within plumes and within rubble piles. The principal purpose for this sampling strategy was to understand the source emissions of VOCs from the WTC rubble and fires, and to alert the Fire Department of New York (FDNY) and the contractors/union health/safety officers working at Ground Zero about conditions that posed immediate health concern to the workers. As such, these data were deemed not appropriate for evaluating human exposure and potential health impacts. Second, analyses of exposure of Ground Zero workers to VOCs were conducted by the Occupational

Safety and Health Administration (OSHA) and the National Institute for Occupation Safety and Health (NIOSH), who employed personal air monitors for their analysis. These monitors are much more appropriate for human exposure assessment. The OSHA data, as posted on their website (http://www.osha.gov), are summarized in Section VI. The NIOSH data are also summarized there, with a reference provided for further information (CDC, 2002).

On the other hand, an evaluation of Ground Zero worker exposure was conducted for dioxin-like compounds. Unlike the case with VOCs, the dioxin monitors were stationary high-volume monitors operating for 8-hour periods. High concentrations captured by these monitors in the few months after September 11 are representative of air quality to which unprotected workers were potentially exposed (i.e, those not wearing respirators). Exposures to asbestos at the Staten Island Landfill were also evaluated using ambient air data. Although workers were not specifically identified as the exposed population, conservative assumptions in an exposure and risk assessment suggest that even continuous exposure for the limited time period when asbestos at the Landfill may have been elevated would not have resulted in exposures that suggest a potential human health risk.

Exposures that were specific to the indoor environment were also not explicitly addressed in this assessment. Section VI describes completed and ongoing studies which have measured levels of contaminants, mostly asbestos, in indoor environments. A major study completed by the Agency for Toxic Substances and Disease Registry (ATSDR) is summarized in that section. Also, EPA Region 2 is currently conducting indoor measurements during the clean-up of residences in lower Manhattan. Clearly, this will reduce future indoor exposures. It is expected that this EPA effort, and future compilations of all available indoor data, will allow for a more complete evaluation of impacts on residents and office workers to contaminants that were present as a result of the collapse of the WTC Towers.

This assessment focuses on the inhalation pathway. Exposure can potentially occur via inhalation, dust ingestion and dermal contact with contaminated dust on surfaces. Dermal contact and dust ingestion were not assessed due to a lack of appropriate data and reliable methods. For residents, contacts with contaminated dust will occur mostly indoors where people spend the majority of their time. The health assessment conducted in this study assumed that ambient air measurements were representative of long- and short-term exposures. In some cases, this could be misleading or inappropriate, particularly if indoor concentrations are higher than outdoor concentrations. It is emphasized that the evaluations in this document focus on ambient, outdoor measurements.

Because of the difficulties in setting up an effective monitoring program in such circumstances, very little data for most chemicals were collected prior to September 18, 2001. As a result, exposures occurring on September 11 and during the week after are poorly characterized. It can reasonably be assumed that the concentrations within and near Ground Zero would have been at least as high and more likely higher than the first measurements taken near September 18. Section V reviews this hypothesis and demonstrates that, for many critical contaminants, the highest concentrations were the first ones taken. The individual contaminant assessments address this lack of data in different ways. For dioxin, it was assumed that the first concentrations measured on September 23 were representative of the period between September

11 and that first measurement. For some chemical classes, like VOCs, an exposure and health evaluation for this time period cannot be conducted because the data do not exist. This could be critical for benzene, for example, which could have been present at very high levels near September 11 due to volatilization from gasoline and aviation fuel. EPA-ORD researchers are working to use modeling and available data and meteorological information to reconstruct probable exposures for some contaminants such as PM. Some preliminary results of plume dispersion are included in this report. When this and other work on immediate post-September 11 issues has been completed, further health evaluations of this critical window may need to be conducted.

Similarly, data regarding contaminant levels prior to September 11, or levels that might be considered background and typical for New York City (NYC), do not exist for all compounds because such measurements have not been performed routinely in all urban areas. Where information specific to NYC is available, such data are discussed. Otherwise, general urban or general background concentrations are identified and used to place the post September 11 monitoring results in perspective.

This assessment evaluates the potential for health impacts from the exposures that have occurred from September through about April of 2002. Most monitoring was discontinued in July of 2002, but data only through April was available at the time this evaluation was conducted. The air concentration data shows that, by April 2002, initially high levels decreased to background levels, with most reaching background by December 2001. However, the data collected between April and July, 2002, will be examined in the coming year to see if there were any elevations which could change the findings presented in this report.

As more data become available, further assessments may be conducted in order to evaluate more chemicals, more pathways, the indoor environment, the period between April and July, 2002, and other identified data gaps. Local and Regional needs, peer review and public comments on this assessment, and professional judgment will be used to determine the direction of future assessments.

Section II. Exposure Assessment and Risk Characterization Approach

Exposure assessments and risk characterizations for all contaminants focus on the inhalation pathway. For most chemicals, potential health risks are evaluated by comparing the measured air levels at locations near Ground Zero to established benchmarks for inhalation exposure and to typical urban background levels. Occupational Safety and Health Administration (OSHA) Permissible Exposure Limits (PELs), National Institute for Occupational Safety and Health (NIOSH) Recommended Exposure Levels (RELs), and Agency for Toxic Substances and Disease Registry (ATSDR) Minimal Risk Levels (MRLs) are among the benchmarks included in this evaluation. Where available, benchmarks established to protect against acute and subchronic exposures are used. Benchmarks that are intended to protect against exposures lasting more than one year or throughout a lifetime, such as EPA's Reference Concentrations (RfCs), were only used if other more appropriate benchmark values were not available. Table 1 provides a summary of the inhalation benchmarks used in this analysis.

EPA's Region 2, in consultation with federal health agencies, also used benchmark values to compare with measured air concentrations. These are described and listed in Appendix A, and are also cited on EPA's WTC web site: http://www.epa.gov/wtc. Region 2 used existing standards where appropriate, and for other contaminants, developed unique standards specifically for the purpose of evaluating the air measurement data from the WTC site. Some of the existing standards which they used included occupational standards such as OSHA PELs, which were used for all site workers conducting response/demolition activities covered by OSHA, and environmental standards such as National Ambient Air Quality Standards (NAAQS: e.g., for lead) and the Asbestos Hazard Emergency Response Act (AHERA) level of concern for asbestos to evaluate monitoring data from the site perimeter and beyond where residents or non-WTC site workers may have been exposed. In cases where appropriate standards did not exist, the Region developed risk-based screening criteria. The risk assessment paradigm detailed in EPA's "Hazard Evaluation Handbook: A Guide to Removal Actions" (HEH; EPA, 1997b) was employed in the development of these risk-based criteria. Screening levels that the Region developed reflect the most current toxicity criteria (Slope Factors and RfCs) on EPA's IRIS database (http://www.epa.gov/iris). The Region developed benchmark values for cancer and non-cancer effects. Details of the Region's derivation procedure are provided in Appendix A.

Some of the benchmarks used by the Region were also used as benchmarks in this report, such as the AHERA standard, while others were not. The unique benchmarks developed by Region 2 for evaluating WTC air measurements were not used in this report. The Region needed to develop and utilize those benchmarks in order to provide daily data reports that were readily understandable. Only existing benchmarks were used in this report, and in some cases, cancer or non-cancer screening exercises that went beyond a simple comparison to a benchmark were employed (e.g., dioxin-like compounds, see discussion below). Efforts are underway within EPA to develop benchmarks and similar standards to evaluate the impacts from a short-term inhalation exposure such as that experienced by some individuals at the WTC site. One such effort entails the development of Acute Exposure Guideline Levels. Final AEGLs are available for some contaminants, such as vinyl chloride, methylene chloride, methyltrichlorosilane, and others, but finalized (or draft) AEGLs are not currently available for the contaminants evaluated in this report.

A simple comparison of an air measurement and a health benchmark can be thought of as a "screening" exercise; the risk assessor is screening for possible problems. If the majority of samples are much less than a benchmark, then in most cases it would be appropriate to conclude that a health impact is unlikely. On the other hand, if most samples exceed the benchmark, then it may be appropriate to consider the possibility that a health impact may have occurred, or could occur, depending on the circumstances.

For dioxin toxic equivalent (TEQ) exposures, the air monitoring data are additionally used to conduct an assessment on cancer and noncancer risk. This involved defining the exposure scenario in greater detail, quantifying exposure within these scenarios for purposes of cancer risk estimation, and modeling the change in body burden over the exposure period for non-cancer assessment. Simple cancer screening exercises are also conducted for PCBs and asbestos. Insufficient information about the other chemicals precluded similar modeling. Where the data allowed, the best possible screening approach appropriate to each chemical class is used to evaluate potential health consequence from measured air concentrations.

In order to characterize exposure and risks, it is necessary to characterize the duration of exposure. Immediately following the collapse of the WTC towers, the NYC Mayor's Office of Emergency Management restricted access to the WTC and surrounding sites. From September 11 through 14, this restricted zone included lower Manhattan south of 14th Street. Figure 1 shows the zones restricted after September 14. The areas in Figure 1 that are identified by a date show when those areas became accessible to the general public. Further details and additional maps can be found at, http://www.nyc.gov/html/oem/html/other/restricted_zones/frozen_zone_history_pdf_page.html. When a zone was restricted, all pedestrian and vehicular traffic was limited to emergency management and rescue personnel and other credentialed people. Residents were not allowed to occupy homes located in the restricted zones. Although some people in certain areas might have come and gone quickly (for example, to collect pets), noone was living or spending a significant amount of time in these areas unless they were part of the rescue, recovery and cleanup operations. As of mid-May, 2002, there were 15 residential buildings in the restricted zone.

As described below, the collapse of the WTC towers resulted in exceedences of screening benchmarks. However, most of these exceedences were in restricted zones and persons who live and routinely work in these areas were unlikely to have been exposed. Regardless of the level of contamination that may be present, if there is no exposure there is no human health risk. In discussions below, the timing and location of all exceedences are identified, and it is noted whether the location was in a restricted zone at the time of exceedence. These restricted zones also influenced the development of "exposure scenarios" that were used in some of the contaminant-specific evaluations.

Table 1. Inhalation health risk screening benchmarks used in this assessment.

Agency	Screening Benchmark	
I. Short-Term Exposures		
OSHA	Permissible Exposure Limit (PEL)	The maximum allowable exposure to a concentration of a substance in the air. PELs are set to protect workers and are based upon an 8-hr time-weighted average exposure. PELs are enforceable standards.
OSHA	Short Term Exposure Limit (STEL)	A 15-minute time-weighted average that should not be exceeded at any time during a workday. STELs are enforceable standards.
ATSDR	Acute inhalation Minimal Risk Level (MRL)	An acute MRL protects against exposures that may last 1 - 14 days. An MRL is defined as an amount of chemical that gets into the body (i.e., dose) below which health effects are not expected.
ATSDR	Intermediate inhalation Minimal Risk Level (MRL)	An intermediate MRL protects against exposures that may last 15 - 364 days.
EPA-STSC	Provisional Subchronic Reference Concentration (RfC)	The STSC subchronic RfC is the exposure level that is likely to protect humans from adverse health effects when exposed over a period not exceeding 10% of their lifetime (usually assumed to be 7 years). These values are only provisional guidance.
ACGIH	Threshold limit value (TLV)	A recommended exposure limit based on an 8-hour workday and a 40-hour work week.
NIOSH	Recommended Exposure Level (REL)	The maximum recommended exposure limit determined to protect workers.
EPA	Asbestos Hazard Emergency Response Act (AHERA) level of concern	This standard was developed to be applied to asbestos in schools. School children were not to be allowed back into an "abatement" area (an area where activities were undertaken to reduce air concentrations) until several consecutive readings were less than the AHERA standard.

Table 1 (cont'd).

Agency	Screening Benchmark	
EPA	Air Quality Index (AQI)	The AQI provides reference points by which (a) to judge increasing levels of concern for potential health effects associated with acute exposures to air pollutants (e.g., particulate matter [PM]) for which short-term National Ambient Air Quality Standards (NAAQS) have been set and (b) to help guide the public and local government officials on actions to minimize unhealthy exposures.
EPA	National Ambient Air Quality Standard (NAAQS)	National air standards set by EPA (under the Clean Air Act) to protect against effects on public health and welfare of major urban air pollutants, e.g., PM. Short-term (24-hr) NAAQS for PM are more relevant here than are long-term (annual average) PM NAAQS.
II. Long-Term Exposures		
EPA	Reference Concentration (RFC)	An estimate of a daily exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of harmful effects during a lifetime.
EPA	Cancer Slope Factor (SF)	An upper-bound 95% confidence limit on the increased cancer risk from a lifetime exposure to an agent. The SF is used in conjunction with a dose term, such as the amount of a chemical inhaled, to conservatively estimate the potential for incurring cancer within a lifetime as a result of that exposure.
EPA	Unit Risk (UR)	The UR factor is used to estimate the upper-bound 95% confidence limit on the increased cancer risk from a lifetime of inhalation to a contaminant. It is derived starting with the SF for a contaminant and then assuming a lifetime of exposure (24 hr/day, 70 yrs). When using the UR, a concentration corresponding to a lifetime average concentration should be used.
EPA	Maximum Contaminant Level (MCL)	The MCL is the highest level of a contaminant that is allowed in drinking water. It is an enforceable standard that is set considering health effects and assuming the best available treatment technology, while taking cost into consideration.

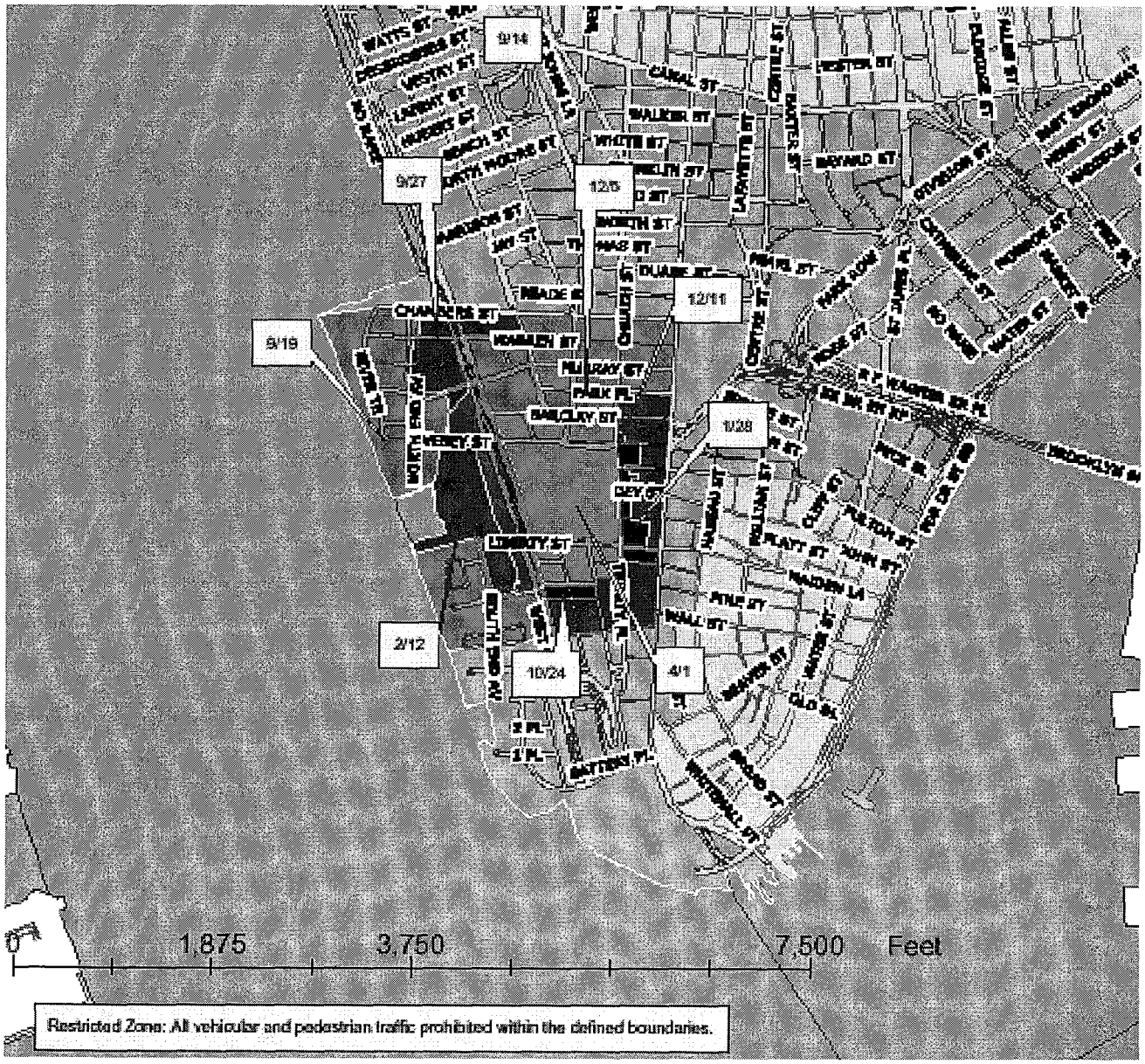


Figure 1. Figure showing the shrinkages of the restricted zones in the vicinity of Ground Zero over time. For example, the area below Canal Street was no longer prohibited after 9/14, and similarly, the shaded area beneath Chambers Street became available only after 9/27. [Figure extracted from map supplied by City of New York, Emergency Mapping Center]

Section III. Environmental Monitoring

Within a month after the disaster, EPA's Office of Environmental Information (OEI) began compiling the monitoring information generated by various agencies and providing that information directly to the public on the EPA web site: http://www.epa.gov/wtc. Environmental monitoring data were made available on a daily basis. EPA also developed three "trend reports," dated November 20, 2001; January 24, 2002; and May 1, 2002. Most of these data were made available to the EPA's National Center for Environmental Assessment (NCEA) in an electronic form for purposes of this report. These three principal sources - the web site, the trend reports, and the electronic data base - represent compilations/interpretations of much of the same data.

The sources of data that have been relied upon in the development of this report are further described below.

- The "EPA WTC monitoring database" In the aftermath of the WTC disaster, many organizations and agencies conducted sampling and monitoring activities to assess environmental impacts. The New York City Department of Health and Mental Hygiene (NYCDOHMH) initially requested that these monitoring organizations forward their results to them so they could be aggregated and made available for internal use by federal, state and local decision-makers. On September 25, 2001, NYC asked EPA to assist in the management of these data by developing a database capable of tracking and reporting on the environmental data. The Agency delivered on September 28, 2001, the EPA WTC Multi-Agency Database that houses data from thirteen federal, state and private organizations (including EPA, the New York State Department of Environmental Conservation (NYSDEC), and the New York City Department of Environmental Protection (NYCDEP) who conducted environmental monitoring after the September 11 disaster. Roughly 95% of all data in the database are from either EPA or the NYSDEC. This database has been maintained by EPA's Office of Environmental Information and provided a clearinghouse and comprehensive site for use by all government agencies responding to the disaster. The database was provided to the authors of this report in May of 2002, and at the time, was current as of mid-April, 2002.

- Environmental Data Trend Report World Trade Center Disaster (EPA, 2002a). These reports have been developed by IT Corporation under contract to EPA's Office of Solid Waste and Emergency Response. IT Corporation has completed reports dated November 20, 2001; January 24, 2002; and May 1, 2002. This latest trends report is current to April 24, 2002. These trend reports focus solely on monitoring data and are summaries primarily of the data included in the EPA WTC monitoring database.

- EPA web site. Most of the data in the EPA WTC monitoring database have been summarized for the general public on the EPA web site dedicated to information on the WTC site (http://www.epa.gov/wtc).

- Historical concentrations of metals, VOCs, PM, dioxin, PCBs, carbon monoxide (CO), nitrogen dioxide (NO_2), and sulfur dioxide (SO_2) for the NYC area provided by EPA Region 2 and found otherwise in the open literature.

- Air monitoring data for VOCs and PM that were not part of the EPA WTC monitoring data base were provided by the ORD National Exposure Research Laboratory (NERL) staff.

- Reports and data developed by non-EPA Agencies involved in sampling at the WTC site, who used the data for their individual purposes. These data sets are described when appropriate and include, for example, the Occupational Safety and Health Administration (OSHA) Sampling Results Summary posted on their web site (http://www.osha.gov) on 8/15/02, the National Institute for Occupational Safety and Health (NIOSH) data base (CDC, 2002), and the Agency for Toxic Substances and Disease Registry (ATSDR) study of indoor residences (NYCDOHMH/ATSDR. 2002).

Appendix B shows a summary of the monitoring stations that provided air monitoring data to the EPA WTC monitoring database that is used in this assessment. Prior to the terrorist attack on September 11, air monitoring stations for PM already existed at a number of locations in NYC, including lower Manhattan, upper Manhattan, Brooklyn/Queens, the Bronx, and Staten Island, as well as New Jersey. Following the disaster, EPA's Environmental Response Team set up monitoring sites at various locations near the WTC. The strategy employed in positioning the various "alphabet" monitoring sites was to place the monitors at varying distances surrounding, but near, Ground Zero. These alphabet monitoring sites are listed first in Appendix B. Pollutants that have been measured at these locations include polycyclic aromatic hydrocarbons (PAHs), dioxins, asbestos, PCBs, metals, silica, and PM. The second major set of monitoring stations listed in Appendix B were established by NYSDEC. These sites have been designated by numbers to contrast with the alphabet sites. Generally, these sites were further from Ground Zero. Pollutants monitored at these sites included particulates, VOCs, dioxins, asbestos, aldehydes, and particle size fractions. In addition, EPA's National Exposure Research Laboratory (NERL) set up monitoring at three of the alphabet sites (A,C, and K) and at site 16 where monitoring generally for particulates (and metals), VOCs and particle size fractions was conducted. Finally, the New Jersey Department of Environmental Protection assisted in the monitoring of asbestos at nearby locations in New Jersey

Laboratories contracted by EPA have conducted most of the pollutant analyses, but EPA laboratories have done some of the analyses, including some of the dioxin and particulate analyses. The EPA laboratories that have participated in this effort include NERL's Human Exposure and Atmospheric Sciences Division (HEAS) in Research Triangle Park, NC, and the Region 7 Environmental Services Division in Kansas City, KS.

Information on the monitoring procedures and the data includes several other details, such as dates of monitoring, different monitoring and analytical procedures, and other issues that are specific to the pollutants. These pollutant-specific issues are discussed in each of the pollutant sections. Also, each section includes a map showing only those sites where monitoring

was conducted for the specific pollutant.

Meteorological stations were also established following the attack. Six stations were set up by the U.S. Department of Interior, and one station was set up by EPA. These meteorological data, in conjunction with monitoring data, are being used by EPA researchers to model and recreate the potential exposures that might have occurred immediately after the collapse of the WTC buildings. Some important preliminary results of the modeling efforts are presented in this report. The overall modeling analysis, when complete, will be presented in future EPA reports and assessments.

In addition to air samples, bulk dust, water, river sediments, and drinking water samples were collected from sites associated with the WTC and surrounding areas to determine the degree to which the disaster may have caused contamination of these media. Sampling and analyses were conducted by various agencies, including but not limited to, EPA Region 2, the United States Geological Survey (USGS), NYSDEC, and the New York State Department of Health (NYSDOH). Between September 11, 2001, and January 14, 2002, more than 150,000 sampling results were reported for the WTC and other New York and New Jersey sites. Results were reported for over 500 substances (statistics from the second of three trend reports; the third is cited as EPA, 2002a).

Although the data generated since September 11 included results for air, bulk dust, water, river sediments, and drinking water, the focus of this evaluation is on the air sampling, with some discussion of the bulk dust as it relates to asbestos and other contaminants. It should be noted that none of the drinking water samples were found to have concentrations that exceeded any of EPA's Maximum Contaminant Levels (MCLs) for drinking water.

Section IV. Evaluation

A uniform approach to characterizing the impacts of all pollutants is not possible because the available background data and screening benchmarks vary between compounds. Similarly, the relevance of these data for the circumstances of exposure following the WTC disaster also varies with the type of contaminant being evaluated. When benchmarks are available for the circumstances at hand they provide a quantifiable approach for assessing the impact of human exposure. Such benchmarks are used and described, as appropriate.

Background or pre-existing levels of environmental contaminants provide an important reference point for describing the environmental impact of the destruction of the WTC. If the monitored levels for a pollutant after the disaster did not appreciably exceed values commonly found in New York or other urban settings, concerns about elevated health risks will be reduced. On the other hand, when contaminant levels are in excess of background, a careful evaluation of the potential health impacts is warranted. Exceedence of background levels does not itself necessarily imply that potential health risks exist. Also, for some pollutants, background measurements might at times show substantial levels and have associated health risks. Thus, comparisons with background levels need to be interpreted in light of the health risk data for the pollutants.

As discussed below, air concentrations and subsequent exposures after September 11 were generally elevated for each pollutant over a limited span of time. Measured concentrations for most air pollutants were reduced by the beginning of 2002. Many of the environmental health criteria have been developed to address "chronic" exposures to contaminants that are present in the environment for years or decades. Exposure levels that exceed a chronic health reference level for a limited period would generally be less likely to result in adverse health effects. Where available, this report has tried to use acute and sub-chronic screening standards. When chronic screening standards are used, the relevance of the comparison is discussed.

In this report, reference is made to OSHA health criteria for the protection of worker's health. These criteria are valuable for the analysis of WTC data for several reasons. Criteria exist for many compounds, not all of which have established environmental health criteria, and they address risks due to less than lifetime exposures. However, there are limitations in applying occupational criteria to evaluations of environmental health risks. Occupational criteria serve to protect relatively healthy worker populations that would typically be less diverse than the general population (in terms of age and health status). Occupational criteria also apply for workday periods, with exposures ceasing during nonworking hours; environmental exposures are typically more continuous. Finally, risk levels that have been accepted in occupational settings may exceed those accepted for long-term environmental exposures to the general population. For these reasons, EPA has not generally used occupational standards as a basis for environmental health criteria.

It is important to reiterate that very limited data are available on the levels of exposure that occurred to individuals due to direct contact with the plume of smoke and dust generated by the WTC collapse on September 11. Such exposures would have been of limited duration, but levels of contaminants may have been significantly higher than those measured in monitoring

programs that have tracked exposures in New York since that time. This is an issue that warrants further examination. Also, the ambient monitoring did not begin immediately on September 12. The earliest reported data are from asbestos monitoring, which began on September 14. The dioxin monitoring did not begin until September 23. It is highly likely that air concentrations within and near Ground Zero were highest during these first several days, but monitoring is unavailable to confirm that hypothesis. This issue is addressed in more detail in Section V, which observes that the highest concentrations were among the first ones measured. Many monitoring programs and studies are currently under way to help us understand health outcomes that have resulted from acute exposures on September 11 and the next several days. These studies are discussed in the final section of this report.

This report should be viewed as the first phase of an ongoing analysis, and the conclusions and findings cited below should not be considered the final EPA judgement. At this point, the available data and analyses are still too preliminary to support reliable quantitative predictions of potential human health risks. Although a complete quantitative evaluation of the health impacts of the disaster may never be possible, future EPA analyses will attempt to develop more quantitative estimates of risks and health impacts using additional exposure-related data and possibly, the results of epidemiological studies that are currently underway. An overview of epidemiological studies that are underway is provided in Section VII.

Following are assessments on the individual pollutants.

IV.a. Particulate Matter

Airborne particulate matter (PM) is a complex mixture of inorganic and organic substances transported in air as solid particles or liquid droplets. PM in ambient (outdoor) air can typically be divided by size into two groups: fine particles (less than ~2.5 μm diameter) and larger, or coarse, particles (ranging from ~2.5 μm to 50 μm or more). Fine PM includes primary particles formed by combustion (including condensed metal and organic vapors), as well as secondary aerosols (formed by gas-to-particle conversions). Coarse PM consists mainly of earth crustal materials formed by natural erosion processes or by human activities such as driving on paved or unpaved roads, agriculture and mining operations, industry, and construction/demolition.

PM exposures and associated potential human health risks are addressed in this preliminary analysis because the collapse of WTC buildings resulted in vast quantities of structural materials and building contents being crushed and pulverized into airborne particles in a wide range of sizes, including both fine and coarse particles. These particles, along with particles and gases emitted from burning jet fuel, aircraft parts, and building debris, formed the immense dust/smoke cloud that rapidly spread across the NYC area and dispersed over hundreds of square miles. Thus, PM air monitoring was essential to help characterize potential health effects resulting from human exposure to the initial dust/smoke cloud, particles produced by the ensuing fires, and reentrained particles stirred up into the air during recovery activities and transport of debris away from the WTC site.

Airborne PM exposures are of concern for human health because they can be associated with a wide variety of adverse human health effects. Some health impacts could include

respiratory effects (such as lung inflammation and exacerbation of asthma) and cardiovascular effects (including exacerbation of preexisting chronic heart disease). As with exposures to other environmental contaminants, potential health impacts depend on PM concentrations and duration of exposure, as well as the size of the particles inhaled and many other factors (including the age and health status of exposed individuals). Depending on age and health status, some groups (such as infants and children, the elderly, and/or individuals with preexisting cardiovascular or respiratory diseases) may be considered sensitive or susceptible populations to possible effects of PM exposure.

Particulate matter is one of six common, widespread air pollutants (the others are ozone, carbon monoxide, nitrogen oxides, sulfur dioxide, and lead) for which EPA has set National Ambient Air Quality Standards (NAAQS). A NAAQS is an air quality standard, set under the Clean Air Act, that is designed to protect public health. In 1987, EPA set PM_{10} NAAQS (150 $\mu g/m^3$, 24-hour average, and 50 $\mu g/m^3$, annual average, averaged over 3 years) to protect against health risks associated with inhalable particles (mainly those < 10 μm diameter) that can deposit in lower (thoracic) portions of the human respiratory tract. These health-related PM_{10} particles include both fine particles < 2.5 μm diameter ($PM_{2.5}$) and a subset of coarse particles larger than 2.5 μm but less than < 10 μm diameter ($PM_{10-2.5}$). After reviewing the scientific bases for PM NAAQS in 1996, EPA concluded that fine and coarse components of PM_{10} particles should be treated as separate classes of pollutants. Thus, EPA moved in 1997 to set an annual $PM_{2.5}$ NAAQS (15 $\mu g/m^3$, annual average, averaged over 3 years) to protect against both short- and long-term exposures and a supplemental 24-hour average $PM_{2.5}$ NAAQS (set at 65 $\mu g/m^3$) to protect against unusually high peak levels to decrease health risks associated with fine particle exposures. The PM_{10} NAAQS were retained to address risks related to coarse particles. As more scientific evidence becomes available, consideration may be given to setting PM standards for shorter averaging periods (< 24 hr).

Also, to provide real-time, day-to-day information to State and local health officials and the public, EPA established an Air Quality Index (AQI) level of concern (LOC) for daily $PM_{2.5}$ ambient concentrations at 40 $\mu g/m^3$. The AQI is meant to provide reference points for judging levels of potential health concern and to guide actions by citizens or government officials to protect the health of the public, including susceptible groups. Thus, in order to minimize risk of potential health effects among highly susceptible individuals (e..g, the elderly over 65 yr old or individuals with preexisting chronic cardiovascular or respiratory disease), actions should be taken to reduce or avoid exposures of such persons to 24-hour $PM_{2.5}$ concentrations above 40 $\mu g/m^3$.

IV.a.1. Air Quality Monitoring of Ambient Particulate Matter Mass/Composition

At the time of the September 11, 2001, WTC attack, there were no monitoring sites measuring ambient air $PM_{2.5}$ or PM_{10} concentrations in the immediate vicinity of the WTC or surrounding neighborhoods in lower Manhattan, except for PM instruments operating at the Canal Street Post Office about a half mile north of the WTC. However, there were numerous New York State-operated PM sampling sites monitoring ambient air PM concentrations at various other locations throughout the five boroughs of New York City (NYC), with most measuring $PM_{2.5}$ levels by Tapered Element Oscillating Microbalance (TEOM) monitors.

During the days following the September 11 events, substantial efforts were made to quickly augment existing PM monitoring capabilities by the addition of PM sampling sites immediately around the WTC Ground Zero work zone and in surrounding lower Manhattan neighborhoods. Of particular note, staff from EPA's National Exposure Research Laboratory (NERL) worked with EPA Region 2 colleagues to set up PM samplers at three surface sites triangulating the WTC Ground Zero work zone perimeter, as shown in Figure 2 (lettered sites A, C, and K). Site A was located at Barclay and W. Broadway just north of Ground Zero, Site C at Liberty and Trinity to the southeast of Ground Zero, and Site K at Albany and West to the southwest of Ground Zero. In addition to these surface sites, ORD PM sampling was initiated at the 16th floor level in EPA Region 2 facilities in the Federal Building at 290 Broadway about six or seven blocks northeast of the WTC. These sites are noted in Table 1 of Appendix B, as EPA Response Team Lettered Sites at Locations A, C, and K and Site #16 under EPA/ORD Numbered Air Monitoring Stations. By October 2, the U.S. EPA Region 2 and EPA OAQPS, along with New York State Department of Environmental Conservation (NYSDEC) personnel, set up PM instruments at Chambers Street, Park Row, and the Coast Guard Building at the Battery, which along with the existing monitors at Canal St., surrounded Ground Zero a few blocks farther out than the ORD sites.

Measurements of ambient air $PM_{2.5}$ elemental composition were made by ORD staff (Vette et al., 2002) at the three ORD surface sites (A, C, and K), using saturation samplers (SS), and on the 16th floor of the 290 Broadway Federal Building, using a modified dichotomous versatile air pollutant sampler (VAPS). The VAPS also collected $PM_{10-2.5}$ samples. Only the battery-powered saturation samplers could be operated within the WTC perimeter because power outages precluded operation of conventional samplers, such as EPA Federal Reference Method (FRM) samplers in use at preexisting NY State-operated PM monitoring sites. Although the SS has been shown (Hill, et al., 1999; also see http://www.airmetrics.com/products/studies/1.html) to achieve accuracy within 6-10% compared to $PM_{2.5}$ FRM measurements at concentrations typically found in ambient air, uncertainty in measured $PM_{2.5}$ concentrations increase as ambient concentrations increase, especially above 100 $\mu g/m^3$ (24-h average). Indeed, even the FRM is subject to increasing uncertainties at high $PM_{2.5}$ levels. However, the general characterization of air quality used for EPA's Air Quality Index (AQI) should be largely unaffected. The use of these samplers (SS) allowed for x-ray flourescent (XRF) analyses of the elemental composition of aerosol samplers. Such XRF analyses were performed on filters collected from September 21, 2001, to January 31, 2002. These samples were collected on an almost daily basis for sampling periods of about 22 hours per day. In addition to the VAPS sampler, high time-resolution measurements of light scattering by particles (which is related approximately to the concentration of fine PM) and light extinction (which is related to the concentrations of black carbon and to complex organic compounds such as PAHs) were also made. The main focus of discussion here with regard to EPA/ORD results is on findings from filter-derived PM mass and elemental composition measurements.

The ORD PM monitoring sites triangulating the WTC Ground Zero perimeter were placed so as to allow: (a) continuous tracking of $PM_{2.5}$ emissions from Ground Zero, useful for detecting any extraordinarily high-level $PM_{2.5}$ exposures to rescue/recovery workers and others operating within or immediately around Ground Zero; and (b) the determination of the physical/chemical composition of WTC-generated PM emissions from the smoldering fires or

recovery operations, which could serve as a "WTC signature" for tracking the movement of the WTC plume and its potential impacts on ground-level air quality in the NYC area. Along with the addition of several more New York State-operated PM sampling sites in lower Manhattan and elsewhere as part of an extended air monitoring network set up by NYSDEC, the ORD 290 Broadway site helped to ensure reasonably good coverage (within feasibility constraints) of lower Manhattan neighborhoods surrounding the WTC Ground Zero work zone. In addition to the ORD monitoring sites (A, C, K, and 290 Broadway), Figure 2 shows the location of New York State-operated $PM_{2.5}$ and PM_{10} sampling sites.

This expanded monitoring coverage greatly enhanced federal/state government capabilities for tracking trajectories of WTC-generated plumes, areas potentially affected by the plumes, and possible WTC-related PM exposures in the NYC area. For example, notable PM increases at ORD Site A (on the WTC Ground Zero north perimeter), coupled with PM elevations at the NYSDEC site at Chambers St. and West St. about 5 blocks north of the WTC (labeled BMCC for Borough of Manhattan Community College in Figure 2) and/or at the Canal St. Post Office would be indicative of a northerly trajectory of the WTC plume and potential surface-level exposures of population groups in the vicinity of those monitoring sites and intermediate locations. Alternatively, marked increases PM levels at Site A, coupled with PM elevations at 290 Broadway and/or PS 64 (~ 2.5 km northeast of the WTC), would be consistent with a northeasterly WTC plume trajectory. Also, any increases in PM levels at Site C, coupled with elevations at Park Row and/or preexisting PM sites at PS 199, the Maspeth Library in Queens, or PS 274 in Brooklyn would be consistent with an easterly WTC plume trajectory; whereas PM increases at ORD Sites C or K, along with PM elevations at Battery Park, would indicate a southerly plume movement. PM increases at multiple ORD sites proximal to the WTC perimeter and in several neighborhoods in various directions from the WTC could also conceivably occur under meteorological conditions involving low wind speeds and thermal stability conditions, producing low mixing layer heights and a more well-defined WTC plume traversing across lower Manhattan or other NYC areas. On the other hand, if PM concentrations at other sites across lower Manhattan or other areas in NYC tend to vary with each other (i.e., go up and down together) and are similar in values, this would imply that they are responding more to urban or regional background sources rather than to emissions from the WTC sites.

To aid in assessing the potential effects of WTC-related air pollutants on air quality in NYC areas, ORD has also embarked on the modeling of the dispersal of WTC Ground Zero-generated plumes, based on prevailing meteorological conditions (e.g., wind speed and direction). This includes: (a) initially, classical Gaussian plume modeling, providing regional-scale hour-by-hour plots that roughly delineate the likely spread and direction of the WTC plume, and (b) more recent initiation of detailed local-scale computational fluid dynamic modeling which is expected to provide improved, detailed estimation of the dispersal of emissions from Ground Zero in the street canyons of lower Manhattan. Some preliminary results of the regional-scale plume modeling are discussed below and compared with PM monitoring results for certain days of particular interest. It is important to note that the preliminary results of the regional-scale modeling primarily allow the estimation of the likely direction and width of the WTC plume at particular times, but they do not alone enable one to conclude if or where the plume may have touched down and resulted in surface-level increases in pollutant levels. They alone also do not allow one to conclude what the PM concentrations would have been, only what

the estimated dilution would have been relative to WTC Ground Zero concentrations. During periods when emissions from Ground Zero were low, any increases in concentrations within the plume would also be low. Other inputs (e.g., evaluation of surface-level PM measurements at various sites and/or photos of the WTC plume) are also needed to aid in characterizing likely occurrences of plumes affecting the surface and/or possible human exposures.

In addition to the above expanded EPA and New York State government PM monitoring and modeling efforts, numerous other investigators (e.g., some from other Federal government agencies, academia, and commercial firms or sponsored by nongovernmental organizations) collected data aimed at in estimating likely PM exposures associated with the WTC attack and ensuing fires and recovery operations. Limited published reports from such studies are becoming available, and a few salient points from these reports are alluded to here. More thorough discussion of these and other reports that become available in the coming months will be included in any subsequent, fuller EPA/ORD evaluation.

One important set of newly available findings are those reported by Lioy et al. (2002), based on work done cooperatively with EPA/ORD and also partly funded by NIEHS. Direct air measurements of the composition of WTC-generated airborne particles by EPA/ORD did not begin until September 21, 2001. Before that date, only bulk samples of settled dust were available for chemical analyses. Lioy et al. (2002) measured the mass of particles in several size ranges in the settled dust and analyzed their composition. Also, detailed chemical analyses of fine fraction particles (< 2.5 μm diameter) from settled WTC dust has recently been reported (McGee et al., 2002). Although the bulk samples do not provide direct data on ambient air PM concentrations, they do provide strong clues as to the likely composition of airborne PM in lower Manhattan and the size distribution of particles in the suspended dust immediately after the collapse of WTC buildings. Small amounts of WTC-derived settled dust were also provided by New York University investigators for laboratory toxicity testing by EPA scientists (EPA, 2002c; Gavett et al., 2002) in EPA/ORD's National Health and Environmental Effects Research Laboratory (NHEERL).

Also, in a cooperative U.S. Department of Energy (DOE)/University of California study, measurements of the size distribution of particles in 10 channels from 0.09 to 12 μm were made on the roof of the Federal Building on Varick Street, using the rotating drum impactor developed at the University of California, Davis (Cahill et al., 2002). This Varick Street DOE site is about 2.0 km north of the WTC (see Figure 2). Sampling began October 2, 2001 and continued into December 2001. Elemental analyses of samples collected approximately every 3 hours were done by synchrotron radiation-induced X-ray emission (SRIXE).

IV.a.2. Particulate Matter Air Monitoring/Modeling Results

1. Particulate Matter Mass Measurements and Plume Trajectory Plots

The collapse of the WTC buildings and the associated fires resulted in the initial dispersion of large quantities of various-size particles in the massive dust/smoke cloud that enveloped lower Manhattan. It is clear from Figures 3 and 4 (and other photographs) that the densest portion of the dust/smoke cloud initially spread in all directions and impacted most of lower Manhattan, especially below Chambers Street. On the basis of the size classifications (by

gravimetric and aerodynamic methods) of particles settled in dust collected September 16-17 at weather-protected sites just east of the WTC, Lioy et al. (2002) reported the largest mass concentrations in the settled dust to be due mostly to particles > 53 μm diameter (~ 51-64% of total mass) and 10-53 μm (~ 35-45% of total mass), followed by lesser percentages for 2.5-10 μm (0.3-0.4% of total mass), and < 2.5 μm (~ 0.9-1.3% of total mass) particles. Given the tendency of large coarse particles to settle out of the atmosphere closer to their emission source(s) than smaller fine particles, it is likely that higher percentages of small coarse particles (> 2.5 but < 10 μm) and fine particles (< 2.5 μm) were more widely dispersed in the plume of dust and smoke that spread primarily to the southeast over Brooklyn and to the south over New York Harbor during the first 18 to 24 hours after the collapse of the WTC buildings on September 11.

Figure 5 shows the results of initial plume dispersion modeling for September 11. The predominant wind direction was to the south-southeast; and this direction continued well into the next day (September 12). As seen in Figure 5, the predominant direction of the modeled WTC plume flow is to the southeast, based on wind directions and speeds indicated by black arrows in this figure. This is consistent with photo images, such as the one shown in Figure 6.

Although no direct measurements of PM concentrations are available for nearby lower Manhattan areas during the collapse of the WTC, some rough estimates can nevertheless be made of what concentrations may have been reached. The dust cloud was optically dense, as can be seen from the airborne images. Under such conditions, sunlight does not reach the surface, and visibilities are greatly restricted. Conditions such as these have been encountered in dust storms and in the London smog episodes of 1952 and 1962 (Elsom, 1992). During such conditions, PM concentrations could have been several milligrams per cubic meter (mg/m^3), i.e., thousands of micrograms per cubic meter ($\mu g/m^3$).

Particles smaller than 2.5 micrometers (fine particles) limit visibility much more effectively than larger (coarse) particles and under conditions usually found in the eastern United States, ambient air concentrations of fine particles are typically higher than those of coarse particles. As a result, under these conditions, visibility reductions are caused mainly by fine particles. There are a number of simple formulas that relate visibility to the concentration of $PM_{2.5}$, such as one from Stevens, et al. (1984):

$$0.5 \text{ (km- mg/m}^3\text{)} = \text{Vis (km)}^* \text{ C (mg/m}^3\text{)} \qquad (1)$$

where V is the visibility range (km) and C is the concentration of $PM_{2.5}$ (mg/m^3). During the collapse of the WTC towers, visibilities were reduced to less than 100 m (about 1 city block) on many streets. If we assume that visibility on streets in lower Manhattan affected by the dust cloud (see Figure 3) was controlled by fine particles, then application of the above formula indicates that $PM_{2.5}$ concentrations could have been about 5 mg/m^3 (5,000 $\mu g/m^3$). However, the collapse of the World Trade Center towers mainly produced coarse particles (Lioy et al., 2002), that, as mentioned above, are less effective than fine particles in controlling visibility. Thus, the values given above represent lower limits on the abundance of total PM. It should also be noted that the above estimate of visibility is based on the loss of contrast between light and dark objects. In many streets, sunlight was blocked and, hence, total PM concentrations could have

been much higher than the lower limit given above, perhaps even approaching concentrations of condensed water vapor that are observed in dense fogs (i.e., thousands of $\mu g/m^3$).

Thus, individuals engulfed in the initial dust/smoke cloud may have been exposed for several hours to concentrations of both fine and coarse inhalable particles anywhere in the range from milligrams per cubic meter (> 1,000 $\mu g/m^3$) to perhaps hundreds of milligrams per cubic meter (> 100,000 $\mu g/m^3$). However, it does not appear that people outside the lower Manhattan area (except possibly very briefly for those on Governor's Island or in Brooklyn Heights) experienced such extreme PM exposures. This estimation is based, for example, on hourly $PM_{2.5}$ levels observed at several NYSDEC monitoring sites (Figure 7) during September 11 to 13. Of most note, as seen in Figure 7, $PM_{2.5}$ concentrations at NYC sites generally remained under 25 $\mu g/m^3$ during most of September 11 and 12. However, hourly $PM_{2.5}$ concentrations did increase to the 50-100 $\mu g/m^3$ range for a few hours on September 12 and 13 at PS 64, which is located about 2.5 km northeast of Ground Zero, and at PS 199, which is located in Queens several miles east-northeast of Ground Zero. These $PM_{2.5}$ increases most likely reflected east-northeast dispersal of not only windblown fine PM from settled dust but also probably of newly formed fine PM generated by the intense fires (> 1000 °F) at WTC Ground Zero. This would be consistent with dispersal to the east-northeast of the WTC plume, as indicated by the ORD modeled trajectory plotted for September 13 (shown in Figure 8). The increased hourly $PM_{2.5}$ levels at PS 64 and PS 199 (reaching 166 and 100 $\mu g/m^3$ at 9 a.m. September 13) indicate that the WTC plume likely briefly fumigated the surface for a few hours at those and/or intervening locations during the morning of September 13.

Changes in wind direction later in the day on September 13 resulted in rotation of the WTC plume back to a flow predominantly to the south-southwest (mainly over New York Harbor) through September 14 and 15, as indicated in Figures 9 and 10. Note the very low $PM_{2.5}$ hourly values (almost all < 6 $\mu g/m^3$) at NYSDEC monitoring sites throughout the NYC area following rain associated with a frontal passage and, also, likely reflecting in part decreased vehicular traffic in the aftermath of September 11 events.

During the next several days, ORD plume dispersion modeling indicates that the plume rotated in such a manner as to result in transport in varying directions, including sometimes to the north-northwest (over northern New Jersey and NYC areas), but there was little indication of the plume fumigating the surface, based on surface PM measurements at preexisting PM monitoring sites. During the rest of September and on into October, 24-hour $PM_{2.5}$ values at preexisting NYSDEC monitoring sites did not exceed the daily $PM_{2.5}$ NAAQS (65 $\mu g/m^3$, 24-h). In fact, daily $PM_{2.5}$ values from most pre-existing fixed sites throughout the NYC area did not show marked elevations in comparison to historical $PM_{2.5}$ levels for NYC areas, with the occurrence through mid- to late October (from time to time or from site to site) of a few 24-hour $PM_{2.5}$ values approaching the 24-hour AQI LOC (40 $\mu g/m^3$) not being notably out of line with past frequency of such excursions in NYC.

Starting September 21, the EPA/ORD WTC perimeter monitoring sites at Sites A, C, and K (within 100-200 meters of Ground Zero) allowed tracking of WTC-related ambient PM emissions in the immediate WTC vicinity. The ORD monitoring data, shown in Figure 11 (top) showed widely varying PM concentrations across the WTC perimeter sites from day to day, with

high hourly or daily $PM_{2.5}$ levels being seen at one or another perimeter site downwind from Ground Zero on given days. As seen in Figure 11, exceedances of the 24-hour $PM_{2.5}$ NAAQS level (65 $\mu g/m^3$) occurred at some Ground Zero perimeter sites during late September and into October, but on only a few occasions thereafter. A general downward trend in daily PM concentrations, as well as a decreasing range of 24-hour variations, were seen for $PM_{2.5}$ concentrations at these WTC perimeter sites from early October, 2001, onward. The range of 24-hour values among these ORD sites generally remained below the AQI LOC of 40 $\mu g/m^3$ during December, 2001, and January, 2002 (as depicted by black bar in lower right of Figure 11 top panel). In contrast to the results seen for the ORD/WTC perimeter sites, distinctly lower $PM_{2.5}$ concentrations were observed at the 290 Broadway site about six blocks northeast of Ground Zero. The 24-h $PM_{2.5}$ concentrations recorded there by VAPS sampling exceeded 65 $\mu g/m^3$ (daily $PM_{2.5}$ NAAQS level) only once, on October 4; and the 24-h AQI LOC (40 $\mu g/m^3$) for highly susceptible persons was approached or exceeded at the 290 Broadway site on only a few occasions (e.g., Sept. 27; Oct. 3, 4, 5; Oct 20; Nov. 15-16). These daily values often reflect high hourly values occurring overnight mainly during early morning hours before 7 or 8 a.m. The overall pattern of results from ORD perimeter monitoring stations near the WTC, coupled with distinctly lower $PM_{2.5}$ concentrations monitored by ORD on the 16th floor at 290 Broadway (about 6 blocks northeast of the WTC) suggest occasional short-term increments in fine PM values at WTC Ground Zero and, at times, along the WTC fire plume path (with areas impacted shifting with prevailing winds).

For example, when low wind speeds and mixing layers associated with a high pressure system over New York City area occurred during October 3-5, generally increased region-wide $PM_{2.5}$ levels were observed across much of northern New Jersey and New York City, with some additional PM increments being superimposed at a few monitoring sites within modeled WTC plume dispersion areas. During such weather conditions, plumes tend to be more well-defined than if there were turbulence and are more identifiable for longer distances (see Stull 2000, for example). In particular, 24-hour $PM_{2.5}$ at WTC Site A (on north perimeter of Ground Zero) reached 400 $\mu g/m^3$ on October 3-4, but 24-hour $PM_{2.5}$ values dropped off to 90 $\mu g/m^3$ at the 290 Broadway site several blocks northeast of WTC and to 53 $\mu g/m^3$ at PS 64 about 1.5 km further to the northeast of WTC Ground Zero and only reached 60 $\mu g/m^3$ at Site K (on southwest perimeter of Ground Zero). This was consistent with prevailing winds (to the northeast) and the modeled plume dispersion depicted in Figure 12 for October 4.

Daily average $PM_{2.5}$ data obtained at additional sites in lower Manhattan (Chambers St., Park Row, and the U.S. Coast Guard Station at Battery Park) are shown in the lower half of Figure 11. These sites are located from 3 to 10 blocks to the north, east, and south from the WTC (see Figure 2). It can readily be seen in Figure 11 that concentrations of $PM_{2.5}$ were much lower than found at the WTC perimeter, indicating a very rapid decline with distance from Ground Zero. $PM_{2.5}$ concentrations at these three sites can also be seen to go up and down together. Correlation coefficients between pairs of these sites are all > 0.9; and the concentrations are all very similar, suggesting that these sites were responding mainly to variations in urban and regional background sources rather than to WTC emissions. None of the daily $PM_{2.5}$ values exceeded the 65 $\mu g/m^3$ $PM_{2.5}$ 24-hr NAAQS. Only a few daily $PM_{2.5}$ values, as seen in Figure 11 and listed in the WTC Environmental Data Trend Report (EPA, 2002a) for the NYSDEC lower Manhattan sites to the north, east, and south of the WTC even approached

the 40 $\mu g/m^3$ AQI LOC value; many of the 24-hour $PM_{2.5}$ levels for such sites were below 20 $\mu g/m^3$. PM_{10} values (not graphically depicted here) observed at the same NYSDEC lower Manhattan locations around the WTC were also consistently below the daily $PM_{2.5}$ NAAQS (150 $\mu g/m^3$, 24-h) and showed a general decreasing trend from October 1 to November 30 and beyond, with 24-hour values decreasing from ~ 50-90 $\mu g/m^3$ at some sites in early October to generally less than 50 $\mu g/m^3$ in November (except for ~114-135 $\mu g/m^3$ on October 25-26 for Park Row and 55-75 $\mu g/m^3$ on November 15-16, 2001 for all the sites).

Overall, then, the $PM_{2.5}$ data appear to support the following conclusions:

(1) Notable $PM_{2.5}$ elevations occurred in the immediate vicinity of the World Trade Center Ground Zero during late September/early October, with concentrations at ORD WTC perimeter sites on some days exceeding the 24-hr $PM_{2.5}$ NAAQS. However, PM concentrations at the WTC perimeter sites fell to typical background levels by late November/early December, 2001.

(2) Such high $PM_{2.5}$ elevations were not observed at other lower Manhattan monitoring sites within 3 to 10 blocks of WTC Ground Zero. On only a few sporadic occasions did daily $PM_{2.5}$ concentrations approach or exceed the AQI LOC (40 $\mu g/m^3$) at one or two sites (e.g., 290 Broadway or PS 64) along the WTC plume path in addition to elevations seen at WTC perimeter sites. The frequency of such excursions were not out of line with historical frequency of $PM_{2.5}$ values approaching or exceeding 40 $\mu g/m^3$ either before the Sept. 11 WTC attack or since the WTC fires ended. See Figure 13, for example, where post September 11 $PM_{2.5}$ 24-h values for PS 64 are compared to historic levels seen at PS 64 during the previous two years.

(3) No notable elevations in $PM_{2.5}$ concentrations were seen at NYSDEC lower Manhattan sites located 3-10 blocks to the north, east, and south from the WTC, with no $PM_{2.5}$ values exceeding either the $PM_{2.5}$ daily NAAQS or the AQI LOC from the start-up of PM monitoring on October 1 onward.

2. Measurements of Particle Composition

Analyses of bulk samples of dust produced by the collapse of the WTC towers were performed by EOHSI at Rutgers University (Lioy et al., 2002). Two bulk dust samples were collected on September 16 and another on September 17. The samples were collected at weather-protected sites located less than 1 km to the east of the WTC. The particle samples were separated according to size by aerodynamic and gravimetric methods. As noted earlier, results of the aerodynamically separated samples indicate that only a very small fraction (about 1%) of PM was in the $PM_{2.5}$ size range and less than 0.5% was in the $PM_{10-2.5}$ size range. The overwhelming fraction of the mass of PM was found in settled dust particles larger than 10 μm. Most of the mass consisted of pulverized building and construction materials such as cement and glass fibers and office building materials such as cellulose. High concentrations of inorganic constituents such as silica, calcium, and sulfate components of building material and metals such as lead and zinc, were found. Also, total polycyclic aromatic hydrocarbons (PAHs), which are products of incomplete combustion, constituted more than 0.1% of the total mass of dust. The fraction of adsorbed PAHs in each size fraction is expected to be roughly related to the relative surface area in each size fraction. According to this criterion, smaller particles would have contained proportionately greater concentrations of PAHs than indicated by their relative

mass.

Lioy et al. (2002) provides complete descriptions of numerous other specific compounds that were found in dust particles that settled outdoors. They also noted that penetration of substantial quantities of WTC-derived dust into indoor office or residential spaces likely notably increased the potential for indoor exposures (via ingestion or by inhalation of re-entrained particles) to high levels of constituent elements and compounds.

More detailed chemical analyses have been performed on aerodynamically size-separated $PM_{2.5}$ derived from bulk dust samples collected on September 12 and 13 from several locations withing 0.5 miles of Ground Zero (EPA, 2002c; McGee et al., 2002). These analyses showed that calcium sulfate (gypsum) and calcium carbonate (calcite) were major components of the fine fraction, indicating that very finely crushed building materials were still dominant components even in this size range. Fine particles more easily penetrate into offices and residential spaces and thereby contribute to indoor exposures more readily than coarse particles.

Data for EPA/ORD measurements of PM elemental composition of fine particles ($PM_{2.5}$) for samples collected starting September 21 are graphically depicted in Figures 14 to 18. The elements are grouped in each figure roughly according to their relative abundance in the subject air samples, those in Figures 14 to 16 being among the most abundant and those in Figures 17 to 18 being distinctly less abundant. Most of the elements shown in the figures were well correlated ($r > 0.85$) with each other at individual sites, with several being much more highly correlated ($r > 0.95$) with each other and with $PM_{2.5}$ throughout the sampling campaign. The very high correlations suggest a common source origin for these elements, that is, WTC fires. The composition of the emissions from Ground Zero combustion sources changed with time as evidenced by initial peaks in several elements (e.g., calcium, potassium, sulfur, chlorine, bromine, lead, copper, and zinc) during late September and early October (Figures 14 to 16), followed by later peaks in the concentration of chromium, arsenic and antimony during mid- or late November (Figures 17 and 18). The elements for which data are depicted in Figures 14 to 18 were selected for illustration from a larger set measured by ORD, based on evident elevations of their concentrations over typical background levels at some point during the sampling campaign.

Consistent with Lioy et al.'s finding of highly enriched calcium in both fine and coarse fractions of settled dust near the WTC, markedly increased levels of calcium continued to be seen in airborne fine particles (Figure 14) at ORD's Ground Zero perimeter sites off and on throughout September and October and much of November, decreasing to low background levels by late November. Elevated levels of calcium in the fine fraction are indicative of highly pulverized building materials (e.g., wallboard) from the WTC site. However, except for a few occasions (e.g., on October 6), airborne fine PM calcium levels were not markedly elevated above background levels at the EPA 290 Broadway site a few blocks northeast of Ground Zero, whereas calcium in the $PM_{10-2.5}$ coarse fraction (not graphically depicted here) did show rather frequent elevations at the 290 Broadway site but decreased to low background levels by the end of November.

Fine PM silicon elevations were only evident briefly during October 3-5 at Location A

and at the 290 Broadway site, in contrast with coarse ($PM_{10-2.5}$) silicon elevations (generally in the 1000-3000 ng/m^3 range) seen at 290 Broadway on a number of days well into late November. The coarse fraction calcium and silicon enrichments most likely reflect (a) windblown re-entrainment of calcium and silicon-contaminated dust remaining on rooftops or window ledges, for example, after hazardous material cleanup of WTC-derived dust in lower Manhattan during the two weeks after September 11, and/or (b) calcium and silicon particle re-entrainment into ambient air associated with WTC recovery operations and transport of debris away from Ground Zero.

Data for concentrations of elemental carbon and total organic compounds in the aerosol phase based on analyses of paired filter samples are not yet available. However, ORD nephelometer results and the results of analyses of bulk dust composition mentioned below suggest that the WTC emissions contained substantial quantities of carbon produced by incomplete combustion. Surprisingly low total carbon levels (1.5 to 8.5%) were found in aerodynamically size-separated $PM_{2.5}$ samples from the bulk dust samples collected on September 12 and 13 (McGee et al., 2002). These results indicate that crushed building materials were the dominant sources of fine PM immediately after the collapse of the towers, whereas combustion from ongoing fires was a relatively more important source of $PM_{2.5}$ in later emissions from the WTC disaster site. Potassium enrichments were also especially notable for ORD Site A measurements into early October (consistent with combustion of organic materials such as wooden furniture, paper, etc.); but much lower potassium concentrations occurred at 290 Broadway, and air levels of potassium at all ORD sites returned to very low background levels by late November.

Elevations of sulfur, chlorine, and bromine (shown in Figure 15) were clearly evident at ORD Ground Zero perimeter sites and sometimes at 290 Broadway during late September and decreasingly so into October, again consistent with the notable enrichments seen by Lioy et al. in WTC dust particles. The sulfur was likely in oxidized form, some perhaps having been converted from primary emissions of SO_2 into secondary sulfate particles, consistent again with both reports of elevated sulfate levels in settled WTC dust particles (Lioy et al., 2002; McGee et al., 2002) or airborne particles (including very fine fraction particles) collected at the DOE Varick St. site on October 3 (Cahill et al., 2002). Also consistent with the Lioy et al. findings of chlorine and bromine enrichments in WTC settled dust are ORD measurements of unusually elevated chlorine and bromine at Ground Zero perimeter sites. The WTC sources of these halides are not clear, but chlorine from burning plastics is not unlikely. The specific enrichment in fine particles of chlorine (versus more typical sodium chloride present as coarse particles) and no notable sodium enrichment rule out attribution of the chlorine levels simply to airborne sea salt influxes into the WTC fire site.

As seen in Figures 16-18, lead and certain other metals (copper, zinc, antimony, palladium, and cadmium) were notably elevated on some days in late September and into early October at EPA/ORD Site A, as compared with concentrations at Sites C and K, but the concentrations of these metals had generally decreased to background levels by mid-October. The late September/early October elevations at Site A on the WTC north perimeter indicate that the WTC fires were likely a common source of emissions of these metals, because the winds were mainly from the southwest at this time. The detection of elevated levels of arsenic and

antimony in mid-November at ORD Site K on the southwest perimeter of Ground Zero (but not at Sites A or C or at 290 Broadway to the north, northeast, or southeast of the WTC) suggests both a different source of WTC fire emissions and a likely climatic shift to winds flowing mainly from the north/northeast to the south/southwest. The chromium elevations seen around November 20, mainly at Site C, suggest possibly yet another later shift in the composition of Ground Zero sources of WTC-generated airborne particle emissions. Hence, the "WTC signature" appears to have varied over time in terms of its specific elemental composition.

In contrast to the above patterns of element levels which indicate that they may have originated from the WTC fires, the gradually increasing concentrations of nickel up to a range sustained during December and January (after the WTC fires were out) seem to argue against any notable airborne fine-particle nickel emissions from the WTC fires subsequent to the collapse of the WTC buildings on September 11. Still, enrichments in samples of settled dust from sites east of the WTC (Lioy et al., 2002) are likely indicative of nickel having been among the metals present in high concentrations of airborne particles in the initial dust/smoke that enveloped lower Manhattan on September 11. This raises the possibility of (a) any remaining nickel-containing dust being re-entrained into outdoor air during later rescue/recovery operations and/or (b) continued elevations of nickel concentrations in WTC-derived indoor dust and re-entrained indoor air particles.

3. High Temporal Resolution Analyses

The ORD $PM_{2.5}$ and associated element measurements discussed above were obtained over sampling periods of close to 24 hours. Examination of additional data is necessary to determine more precisely the duration and nature of enhanced concentrations of PM constituents and to help understand possible public health impacts of such excursions. For example, of much interest are PM elemental composition data for the period October 3-5, when a high pressure system settled over New York during the early morning hours of October 3 and 4. Concentrations of sulfur were close to six times higher at the downwind ORD WTC site (Site A) than at the upwind site (Site K) on October 4. Concentrations of a number of other elements were also much higher by large enrichment factors at Site A as compared to Site K, as indicated by the enrichment factors (noted in parentheses) for the following elements: silicon (41X), chlorine (500X), potassium (47X), calcium (5X), bromine (350X), copper (130X), zinc (110X), palladium (> 100X), cadmium (>100X), antimony (>100X), and lead (66X). Overall, the above results are most consistent with brief, episodic increases from WTC Ground Zero during early morning hours on October 3 and 4 leading to elevated concentrations of PM and its constituent elements at WTC perimeter sites and one or another sites in lower Manhattan located downwind of the WTC on those days (i.e., to the north and/or northeast). These enhanced concentrations were superimposed on generally higher concentrations of PM and its constituents found upwind of the WTC on those days. The higher concentrations found at the upwind sites were associated with a high pressure system that settled over the New York Metropolitan Area during that period. In any case, the results suggest strongly that the WTC site was the dominant source of these elements on October 3-4.

University of California, Davis measurements (Cahill et al., 2002) on the roof of the DOE building indicate a sharp increase in concentrations of $PM_{2.5}$, mainly in the size range between 0.34 to 0.56 μm on the morning of October 3, as shown in Figure 19. This very brief excursion

only lasted a few hours. Concentrations of sulfur and silicon at this time were notably elevated at the DOE site as compared to days immediately before and after. Also, ORD data collected by both the nephelometer and the aetholometer sited on the Federal Building at 290 Broadway indicated substantial elevations of PM and light-absorbing components within the space of a few hours early in the morning of October 4. Hourly $PM_{2.5}$ levels at PS 64 were also elevated (some in excess of 100 $\mu g/m^3$) during or shortly after the same hours on October 4, suggesting brief surface fumigation by the WTC plume to the north-northeast of Ground Zero.

It has been suggested that the high concentrations of sulfur observed at the DOE building on Varick Street were related to transport from power plants either in the Northeast or in the Ohio Valley. During this early October period, there were most probably some increases in the concentration of sulfur associated with regional scale transport of sulfates derived from distant sources. However, the extremely high abundance of sulfur at Site A on the Ground Zero perimeter observed by ORD and the ratio of sulfur observed at Site A compared with that observed at Site K suggests that Ground Zero was a large source of sulfur on October 3 and could have also contributed to sulfur readings at the DOE rooftop site.

The peak elevations of airborne fine PM silicon limited to October 3-4 at Site A and at 290 Broadway are notable, suggesting high temperature volatilization of silicon from glass and/or cement by intense WTC fires on those dates and transport of the WTC plume in a north to northeasterly direction. This is consistent both with the plume trajectory plotted in Figure 12 and the marked increases in silicon levels reported by Cahill et al. (2002) at the DOE Varick Street site, to the north-northeast of the WTC, including unusual measured elevations of silicon in very fine (0.09-0.50 μm) and, possibly, inferred ultrafine (< 0.01 μm) PM size ranges (silicon otherwise typically being mainly associated with coarse fraction particles > 2.5 μm). There were also marked increases in ORD-observed concentrations of various metals on October 3-4, reinforcing the conclusion that the DOE Varick Street data for October 3 reflected emissions from intense Ground Zero fires. The very brief increase in $PM_{2.5}$ values and high levels of silicon at the DOE site on October 3 apparently did not occur again at that site, based on preliminary EPA evaluation of the Cahill et al. raw data provided by DOE (Figure 19). Interestingly, Lioy et al. (2002) reported lead and other substances as being unusually congealed together with silicon in particles from the WTC settled dust, likely due to the vaporization of silicon, lead, and/or other metals by intense heat, followed by their condensation and coagulation into particles with unusual composition.

The above high-resolution measurements suggest that WTC emissions in late September and early October varied greatly at times over 24-hour periods and that some of the more notable emissions probably occurred in discrete events which resulted in air pollutant elevations that lasted only a few hours (mainly overnight during cooler early morning hours before temperature increases after sunrise). Such events were likely related to activities of rescue and recovery operations at the WTC, such as removal of large pieces of debris perhaps resulting in increased oxygen flow and brief flareups of fires within the WTC rubble pile. Further high temporal resolution analyses, including more detailed local-scale WTC plume plots, will be needed to better understand the specific lower Manhattan areas impacted by short-term WTC emission events and the implications of these sporadic events for potential human exposures and health impacts.

IV.a.3. Evaluation of Potential Particulate Matter Human Exposures and Health Impacts

Because no direct measurements were obtained for airborne particle concentrations present in the dense dust/smoke cloud that enveloped lower Manhattan for up to about 4 hours after the collapse of the WTC buildings on September 11, estimates of likely exposures to airborne PM for individuals caught in the initial dust/smoke cloud can only be deduced from indirect evidence and are subject to great uncertainty. Nevertheless, several tentative conclusions appear to be warranted on the basis of available inputs thus far.

First, it is likely that many persons caught outdoors (or some even indoors) in the initial dust/smoke cloud were exposed for several hours to extremely high levels of airborne particles. This exposure probably included inhalation of PM concentrations in the milligrams per cubic meter range, well in excess of 1 to 2 mg/m^3 (1000-2000 $\mu g/m^3$), for *both* fine (PM < 2.5 μm diameter) and coarse (PM > 2.5 μm) inhalable particles. Although there were no measurements available during this critical time period, an examination of available photographs in combination with an empirical relationship based on visibility suggests that concentrations could very easily have been this high and likely were even much higher (e.g., possibly > 5 mg/m^3). Such a finding is also supported by analyses of bulk dust samples conducted by Lioy et al. (2002).

The coarse inhalable particles (PM > 2.5 μm) likely included substantial quantities of particles in the $PM_{10-2.5}$ range, which are capable of reaching lower respiratory tract (thoracic) regions of the lung, even though such coarse particles made up less than 0.5% of the particles found in WTC-derived settled dust by Lioy et al. (2002). Individuals who inhaled such high concentrations of WTC dust particles, even for a few hours, would logically be expected to be at potential risk for immediate acute respiratory and other symptoms and/or, possibly, more chronic health impacts associated with lung deposition of notable quantities of constituent PM materials (e.g., calcium, silicon, potassium, lead, other metals).

Persons exposed to the very high PM levels in the initial dust cloud and who continued to work at Ground Zero or returned to work there within a few days without wearing adequate protective respiratory gear might be at especially increased risk for potential acute or chronic health effects, depending on the extent of any ensuing exposures to high PM levels on or immediately around the Ground Zero rubble pile. The latter could include additional exposures to coarse PM constituents (e.g., calcium or silicon) present in re-entrained dust particles from the initial WTC building collapse and/or exposures to newly formed fine particle constituents (e.g., metals), as well as to organic constituents (e.g., PAHs present in both size ranges) emitted from the WTC fires.

Evaluation of potential health impacts associated with the above types of PM exposures should be further facilitated by disease registry efforts and retrospective epidemiologic analyses of physician/emergency department visits and hospital admission records being sponsored by the Centers for Disease Control (CDC), the Agency for Toxic Substances and Disease Registry (ATSDR), the National Institute of Environmental Health Sciences (NIEHS), and other federal, state, and NYC agencies and that are now under way. Recent reports (Prezant et al., 2002)

indicate that large percentages of firemen caught in the initial WTC dust cloud and others who worked at Ground Zero during the first 2 to 7 days post September 11 experienced respiratory (e.g., "WTC cough" and/or bronchial hyperactivity) or other symptoms that still continue to persist for some individuals several months after cessation of exposures at WTC Ground Zero.

During the week following September 11, the plume from initial high-intensity WTC fires appears to have been largely convected upwards and dispersed mainly to the south-southeast or south-southwest without much evident ground level contact, except perhaps for a few hours on the mornings of September 12 and 13, when it flowed to the east-southeast of the WTC. This resulted in briefly increased hourly $PM_{2.5}$ levels at sites in lower Manhattan (166 $\mu g/m^3$ at PS 64 on 9/13) and in Queens (100 $\mu g/m^3$ at PS 199 on 9/13). Probably few people were exposed around the PS 64 site, given the restrictions in effect on motor vehicular or pedestrian traffic below 14th Street until September 14, but some may have been briefly exposed in the vicinity of the PS 199 site and/or at locations between the two sites. Although it is doubtful that the brief, several-hour $PM_{2.5}$ excursion on the morning of September 13 resulted in harmful PM exposures, retrospective examination of physician and emergency department visits and/or hospital records in the affected areas may help to verify this.

After September 21, EPA/ORD monitoring indicated initially high levels of WTC-derived airborne particles (especially at certain Ground Zero perimeter sites) during late September and early October, but occurrences of PM excursions decreased over time through late October and into November. The rate of decrease in concentrations was not uniform throughout the monitoring period; rather, there were episodes of high PM levels spaced between periods of much lower concentrations. The frequency of the episodes was highest during the first month following the collapse of the WTC buildings and then declined afterwards. For example, notable PM emission episodes occurred during the first month of sampling, as shown in Figure 11. $PM_{2.5}$ concentrations varied over a wide range (sometimes exceeding the relevant AQI 40 $\mu g/m^3$ action level) during late September and early October at EPA/ORD WTC perimeter Site A. The concentrations of a number of elements measured at this site also showed large day-to-day variability, as shown in Figures 14-18. On a number of days in late September and early October, concentrations of several elements were many times higher than the more typical background levels recorded for December-January, after the WTC fires had largely or entirely burned out.

On the basis of overall air quality results summarized above, it appears that 24-hour PM_{10} and $PM_{2.5}$ values throughout most all of the NYC metropolitan area generally remained at or returned rather quickly to historical background levels and WTC PM emissions posed no increased health risks beyond those due to usual PM levels for most areas of NYC. On the other hand, high $PM_{2.5}$ concentrations recorded on the perimeter of Ground Zero during late September and early October may imply increased health risks for the most highly exposed individuals (that is, persons who spent extended periods of time within the WTC Ground Zero work zone without wearing protective respirators). Specifically, acute exposures to irritating materials present in either the $PM_{2.5}$ or coarse particle components of PM_{10}, especially during any high hourly peak excursions, may have contributed to acute or continuing respiratory symptoms reported by some workers and/or residents in lower Manhattan areas in the immediate WTC vicinity. It is much less likely that any markedly increased health risks were posed by ambient air PM exposures

elsewhere in the lower Manhattan neighborhoods surrounding the WTC, although more thorough analysis and modeling of potential PM exposures and correlation with health records is needed to evaluate this issue more fully.

It may be useful to place the above potential airborne PM exposures in perspective by comparing them to (a) exposures that occurred during some past notable PM air pollution episodes and (b) more recent historical data recorded for New York City areas. As discussed in U.S. EPA (1982, 1986a) and Elsom (1992), a number of past severe air pollution episodes involved extended periods of exposure of urban populations to high concentrations of airborne PM and associated air pollutants such as SO_2. In contrast to relatively brief periods (< 8 hours) of September 11 inhalation exposures on September 11, 2001 to concentrations in the range of, and maybe in excess of, 1000-2000 $\mu g/m^3$ of WTC-derived airborne coarse and fine PM, a number of past air pollution episodes in U.S. cities (e.g., Donora, PA in 1948; NYC in 1953 and 1962/63) and internationally (e.g., Neuse Valley, Belgium, 1930; London, UK in 1952, 1957, 1963) involved exposures to very high levels of PM that lasted for at least several days. Probably the most famous such episode occurred in London in December 1952, when millions of Londoners were exposed to daily PM levels (measured as British Smoke, which included high percentages of fine particles) of 1000-4000 $\mu g/m^3$ (sometimes reaching hourly peaks of 6000 $\mu g/m^3$ or more) on 3 to 5 consecutive days in the presence of 1000-4000 $\mu g/m^3$ of SO_2.

In NYC, $PM_{2.5}$ values recorded on some days at the Ground Zero perimeter and occasionally elsewhere in lower Manhattan during late September and early October clearly exceeded the more usual background levels of fine PM seen in NYC since implementation of the PM NAAQS in the 1970s began to substantially reduce ambient PM concentrations in U.S. urban areas. For example, some ORD WTC perimeter site 24-hour $PM_{2.5}$ measurements of more than 100 $\mu g/m^3$ likely exceeded most - but not necessarily all - values recorded at the New York University Medical Center in an aerosol sampling study conducted in August 1976 (Lippman, et al. 1979), as per the mean value shown for $PM_{2.0}$ samples in Table 2. However, the 24-hour $PM_{2.5}$ concentrations (predominantly below 30-40 $\mu g/m^3$) usually seen during most of the rest of October and into November at ORD WTC perimeter sites were notably lower than the 1976 values; and the $PM_{2.5}$ levels reached by December and January generally compare favorably with $PM_{2.5}$ values obtained at a monitoring site at the Bronx Botanical Gardens during February-June 2000. This Bronx site can be considered to be a relatively "clean" urban background site largely free of the effects of strong local sources. Maximum $PM_{2.5}$ values ranged from 35.4 to 43.3 $\mu g/m^3$ from three inter-compared collocated samplers at that Bronx site and average 24-hour $PM_{2.5}$ values ranged from 12.5 to 15.6 $\mu g/m^3$, analogous to the mean $PM_{2.5}$ concentrations shown in Table 2 for Boston and Philadelphia during February-June, 2000. Also, PM_{10} values for lower Manhattan sites, which were mainly in the range of 50-90 $\mu g/m^3$ during October and mostly below 50 $\mu g/m^3$ in November, were not markedly different from historical values observed in NYC. For example, the fourth highest and the maximum 24-hour PM_{10} values reported in the EPA Aerometric Information Retrieval System (AIRS) database for the five NYC boroughs during 1996 to 2001 ranged from 40-89 $\mu g/m^3$ and from 51-121 $\mu g/m^3$, respectively.

During September-October, 2001, concentrations of many elements, including heavy metals, at Ground Zero perimeter sites were at times much greater than those observed at several sites in the Northeast in February-June 2000. As part of a pilot study for EPA's $PM_{2.5}$ speciation

network, concentrations of $PM_{2.5}$ and a number of key elements were measured from February to June, 2000, in NYC (at the Bronx Botanical Gardens), Boston, and Philadelphia, at sites that were likely characteristic of urban backgrounds. As shown in Table 2, the average concentrations of $PM_{2.5}$ and the individual elements measured at the three sites varied relatively little in contrast to those measured near the WTC site. The highest measurements of $PM_{2.5}$ and heavy metals are also shown in Table 2 for comparison. During the first weeks after September 11, $PM_{2.5}$ levels and concentrations of several elements often were many times higher than those obtained at the northeastern sites listed in Table 2. As also seen in Table 2, concentrations recorded at the New York University Medical Center in 1976 (Bernstein and Rahn, 1979) were higher than those at the other Northeastern sites, but they were still distinctly lower than the measurements made soon after September 11.

During December and January, the concentrations of most of the elements measured by ORD decreased to levels similar to those measured at the northeastern sites, suggesting that the WTC was no longer a significant source of these elements. However, it should be noted that even the markedly elevated element concentrations over typical background values noted mainly in September and October did not exceed applicable OSHA PEL (8-hour time-weighted average) values or other more broadly applicable health benchmark values, suggesting a generally low health risk for those working at Ground Zero or others present in lower Manhattan neighborhoods around the WTC.

Alkalinity of the dust from the WTC disaster may have been a possible health concern for exposed individuals. Some reported symptoms (eye, nose, and throat irritation; nose bleeds; cough) may have been due to exposure to unusually elevated quantities of certain crustal materials derived from pulverized concrete, wallboard, and other WTC structural components present in airborne particles and settled dust in neighborhoods near the WTC. The United States Geological Survey (USGS, 2002). Lioy et al. (2002), and McGee et al. (2002) all reported testing aqueous solutions of WTC settled dust and finding an initially high alkalinity (generally $\geq$ pH 10.0), which decreased to pH 8-9 for outdoor samples taken after rainfall (as reported by USGS). Because much of the outdoor settled dust was removed by hazardous material cleanup procedures or was washed away by rainfall during late September, outdoor exposures to highly basic PM components would seem to be of much less potential health concern beyond late September when restricted zone shrinkages allowed more people and traffic in neighborhoods immediately surrounding the WTC work zone. However, USGS noted higher alkalinity for dusts sampled indoors, raising the possibility of greater risk of acute irritation symptoms being associated with indoor exposures to WTC dusts than with outdoor dusts leached by rainfall.

Lioy et al. (2002) more broadly highlighted indoor exposures to WTC-derived dust PM as posing potential increased health risks. Individuals visiting, residing, or working in buildings not adequately cleaned before reoccupation could have been subjected to repeated, long-duration exposure to many of the components from the original WTC collapse found by Lioy et al. in settled dust to the east of the WTC. Lioy et al. noted that long, narrow glass fibers in the WTC-derived dust had various potentially toxic materials attached to them and could contribute to acute short-term irritative effects and possibly to more chronic health risks.

Also of potential concern would be any extended indoor air exposures to finely pulverized

building materials (e.g., calcium, silicon, iron, and sulfate) in PM particles, to PM of either fine or coarse size containing marked elevations of certain metals, or to fine PM containing usual combinations of silicon coagulated with metals or other toxic materials. Lioy et al. directed notable attention to indoor dust loadings of lead as posing potential chronic health risks. The possible contributions of certain other metals (e.g., nickel, chromium) found in settled dusts or airborne PM to irritative symptoms also need further evaluation. The discussions below for lead, nickel, and chromium contain more information on the possible bases for concern with these particular metals. The issue of potentially greater toxicity being associated with unusually increased quantities of very fine or ultrafine particles present in airborne PM also needs to be evaluated further.

Some newly available findings from the laboratory toxicity studies of WTC-derived dusts may offer insights into potential health responses associated with exposures on September 11 to WTC-derived materials in the initial WTC building collapse dust cloud and later exposures to WTC-particles deposited indoors. ORD NHEERL scientists analyzed chemical and toxicological properties of $PM_{2.5}$ derived from the collapsed WTC buildings (EPA, 2002c; McGee et al., 2002; Gavett et al., 2002). Deposited dust samples were collected from sites within a half-mile of Ground Zero on September 11 and 12 and size-separated to collect the $PM_{2.5}$ fraction. Gavett et al. (2002) evaluated responses of young adult female mice to bolus doses of WTC-derived $PM_{2.5}$ dusts administered by intratracheal instillation directly into the lungs and to 5-hour inhalation exposures to WTC $PM_{2.5}$. On the basis of the overall pattern of results obtained, Gavett et al. observed both a small degree of pulmonary inflammation in response to WTC dust, which was distinctly less compared with exposure to residual oil fly ash (ROFA), and some notable increases in airway hyperresponsiveness to methacholine, a nonspecific bronchoconstricting agent, greater than that observed in mice exposed to ROFA or other PM samples. These effects may be interpreted as being consistent with reports of airway hyperresponsiveness and irritant responses in people exposed to high concentrations of WTC-derived dusts. Whereas the mild pulmonary inflammation in mice diminished from 1 to 3 days after exposure, the airway hyperresponsiveness appeared to persist longer.

These results suggest possible limited, short-term lung inflammation effects from exposures to high concentrations of WTC dust (as may have occurred mainly on September 11) or possible long-term airway hyperresponsiveness that might portend more prolonged sensitivities and irritative symptoms for persons experiencing extended high-level exposures to WTC-derived dusts indoors. Gavett et al. (2002) estimated the human exposure equivalent of the doses that led to these responses in mice, and calculated an 8-hour exposure at moderate activity level to a concentration of 425 $\mu g/m^3$ using a multiple-path particle deposition model (Ferijer et al., 1999). Individuals who are especially sensitive to inhalation of dusts, such as asthmatics, might experience these effects at lower concentrations over more prolonged periods of exposure. As mentioned previously, it is likely that persons caught in the initial dust/smoke cloud could have been exposed to $PM_{2.5}$ concentrations in excess of 1000 $\mu g/m^3$. However, a dose equivalent to a human exposure of 130 $\mu g/m^3$ over 8 hours caused no significant effects in the mice, suggesting that most healthy people would not be expected to respond to this moderately high exposure level with any adverse respiratory responses (EPA, 2002c; Gavett et al., 2002).

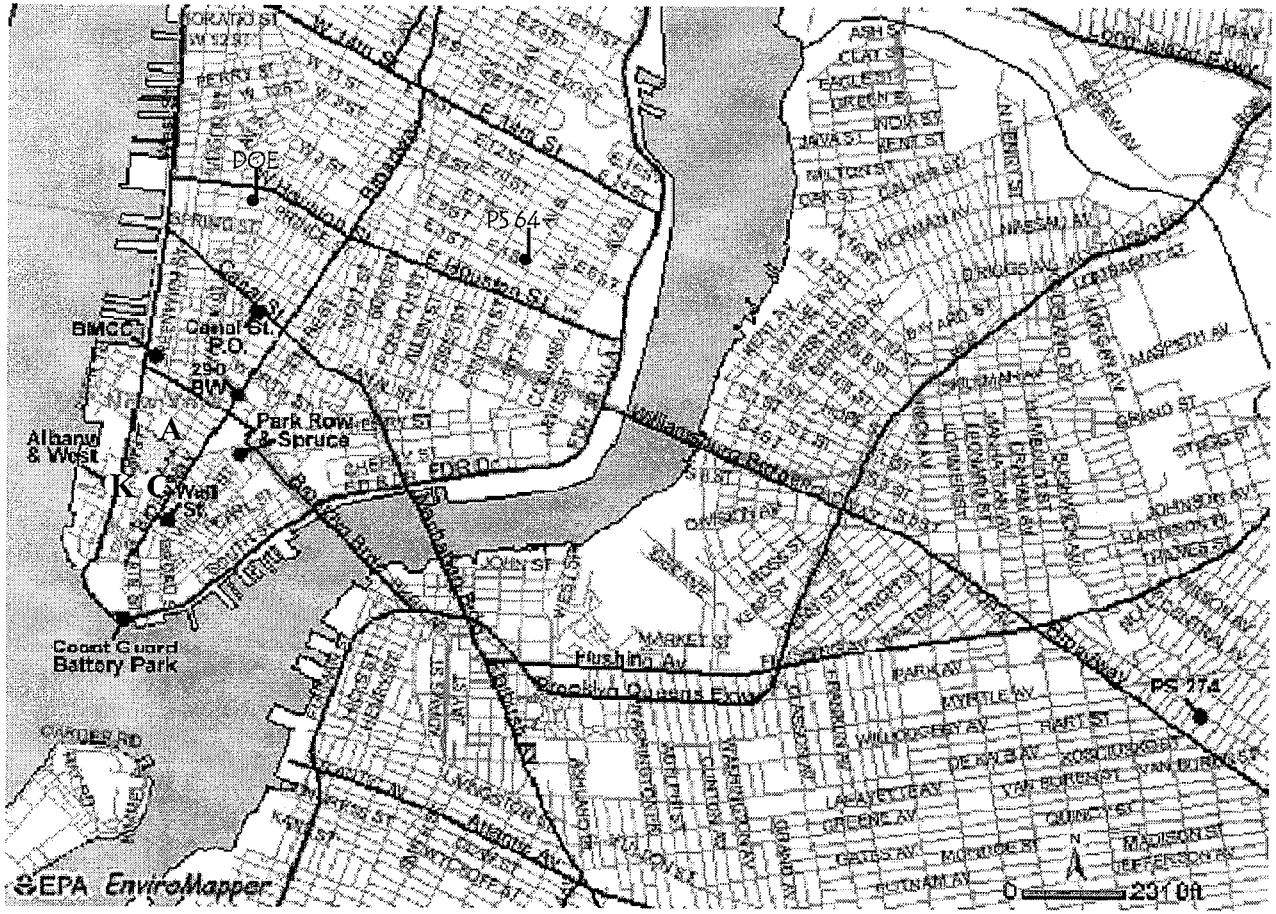
These studies did not address the effects of the coarse fraction of WTC PM on responses in mice, which may be very important, considering the upper airways responses and ocular irritant effects that have been reported.

Table 2. Concentrations (maximum and Sept-Oct average) of $PM_{2.5}$ and Component Elements Measured at the EPA/ORD World Trade Center Perimeter Sites and at Four Other Sites in the Northeast U.S. ($PM_{2.5}$ concentrations in $\mu g/m^3$; all other components in ng/m^3).

	WTC Max. (Site, Date)	WTC Average Sept-Oct[1]			NYU Med. Ctr.[2]	Bronx, NY[3]	Boston, MA[3]	Phila, PA[3]
		A	C	K	Aug '76	Feb-June '00	Feb-June '00	Feb-June '00
$PM_{2.5}$	400 (A, 10/4)	85	34	50	81.7[4]	12.5	10.7	14.7
Na	870 (A, 10/4)	273	157	169	570	72	178	63
Mg	490 (K, 11/13)	101	67	79	103	4.8	16	7.7
Al	670 (A, 10/20)	198	74	113	187	9.2	25	18
Si	20000 (A, 10/4)	943	224	333		75	92	118
S	23000 (A, 10/3)	4796	1808	2524	6820	1200	933	1500
Cl	45000 (A, 10/4)	7247	540	845	119	9.8	68	7.7
K	5600 (A, 9/22)	988	147	260	194	38	38	60
Ca	4900 (A, 10/11)	1304	345	749		38	50	57
Cr	34 (C, 11/19)	5	4	3	28	0.3	0.5	1.1
Fe	9400 (K, 12/12)	1745	904	975	400	91	76	103
Co	24 (A, 10/3)	4	bdl	bdl	3.2	0.4	0.4	
Ni	50 (K, 12/11)	11	9	11	18	12	2.8	4.4
Cu	2800 (A, 9/22)	435	59	92		2.8	2.2	4.5
Zn	10000 (A,10/4)	1526	164	307	224	21	9.7	16
As	1100 (K, 11/14)	9	bdl	bdl	3	1.1	0.9	1
Br	5700 (A, 9/20)	800	82	124	133	2.5	2.5	3.4
Pd	900 (A, 10/4)	132	2	7				
Cd	150 (A, 9/22 & 10/4)	33	9	9	7.7	1.7	1.7	1.8
Sb	350(A, 9/22)	50	2	1	11	3.6	2.4	3.5
Pb	5500 (A, 9/22)	791	83	167	1170	4.2	3.4	5.6

[1]A time series of $PM_{2.5}$ measurements for Site A (as well as Sites C, K, and 290 Broadway) can be seen in Figure 11. Time series measurements for the

elements in $PM_{2.5}$ from the same sites can be seen in Figures 14-18. Measurements in these tables are the high measurements seen in these figures, and the dates of the measurements are shown in parenthesis. Nearly all elevated measurements were seen in Site A, and in late September, early October. bdl = below detection limit and n.a. = data not available. [2]NY Summer Aerosol Study, 1976. [3]Coutant et al., 2001. [4]$PM_{2.0}$ 0.9 * $PM_{2.5}$ (estimated).



Key for ORD Lettered Sites

A = Barclay and West Broadway
C = Liberty and Trinity
K = Albany & West (as noted on figure)

Figure 2. Particulate matter monitoring sites, including ORD surface sites (A, C, K) on the WTC perimeter, the ORD site at 290 Broadway, and NYSDEC sites located elsewhere..

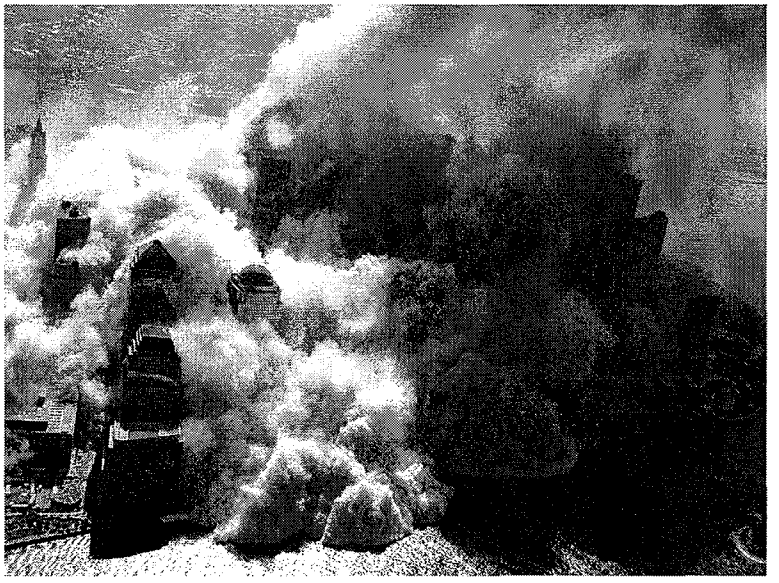


Figure 3. Spread of dense dust/smoke cloud over all of lower Manhattan and drifting to the E/SE immediately after the September 11, 2001, collapse of the World Trade Center buildings.

Figure 4. World Trade Center (WTC) plume from intense fires (>1000 °F) during days following September 11, 2001, with high concentrations of both newly formed fine particles from combustion and reentrained coarse particles likely being transported upward by convection processes and being dispersed in the WTC plume over varying NY City areas, depending on prevailing wind directions and speeds.

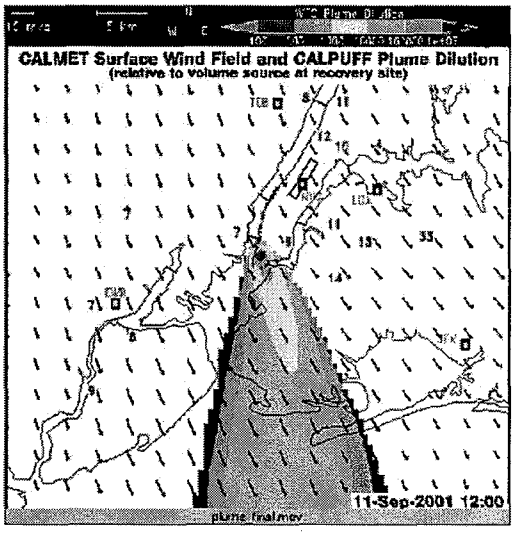


Figure 5. ORD-modeled WTC Plume Dispersion on September 11, 2001 at 12 noon. The values indicated by red numerals are hourly $PM_{2.5}$ concentrations (in $\mu g/m^3$) measured at pre-existing NJ and NY State-operated PM monitoring stations in northern New Jersey and New York City. Red, orange, and yellow shading represent most likely areas of plume dispersion (red = estimated dilution to 100^{th} to 500^{th} and dark blue = dilution to < one millionth of pollutant concentration at WTC source.

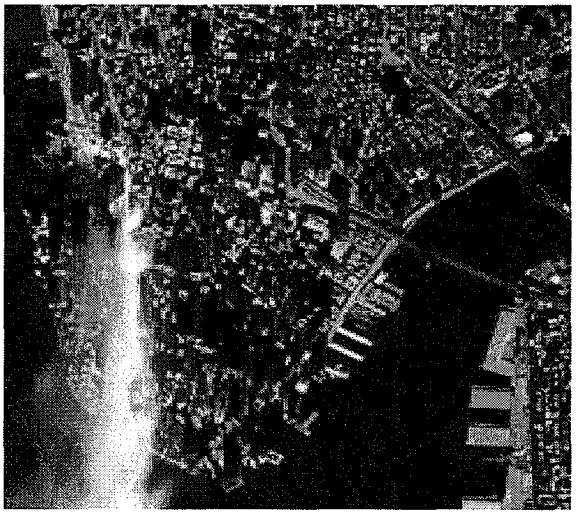


Figure 6. Satellite photograph of the WTC plume lofting from Ground Zero at 11:43 a.m. EDT on September 12, 2001. Note the very concentrated vertical convection of dust/smoke particles upwards and the flow in a well-defined plume towards the S/SE. (Source: Mandatory credit: "spaceimaging.com".)

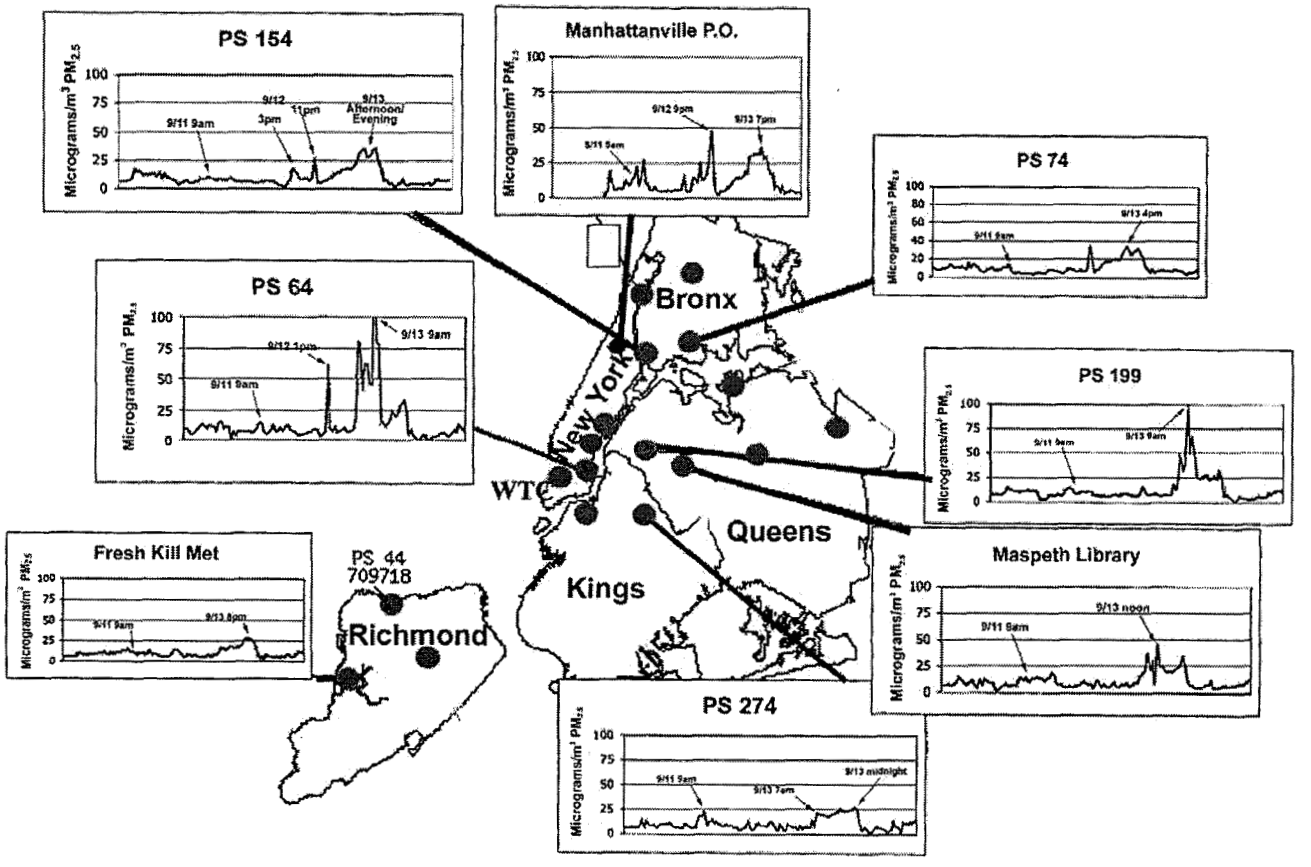


Figure 7. Increased hourly $PM_{2.5}$ concentrations measured on September 12 and/or 13 at PS 64, PS 199, Maspeth Library, and PS 274 to the E/SE of WTC, reflecting dispersal of newly formed fine particles from WTC fires and/or fine particles reentrained from the settled dust from initial collapse of WTC buildings. ($PM_{2.5}$ data provided courtesy of NYSDEC).

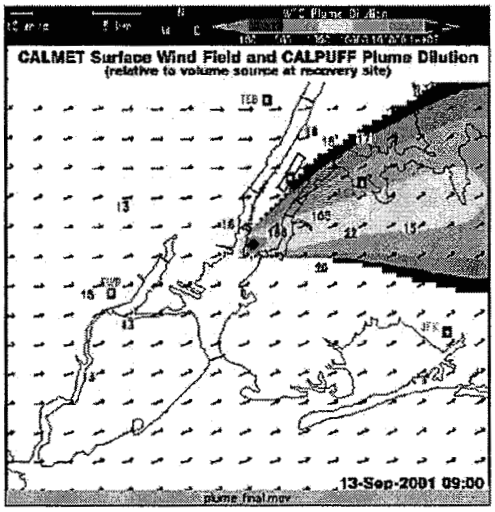


Figure 8. ORD-modeled WTC plume dispersion for September 13, 2001 at 9:00 a.m. Note the increased hourly $PM_{2.5}$ concentrations depicted in red for PS 64 (166 $\mu g/m^3$) and PS 199 (100 $\mu g/m^3$) NYSDEC monitoring stations, consistent with the E/NE direction of the modeled plume dispersion and likely touchdown of the plume at those and intervening sites but not at sites further E, SE, or to the N.

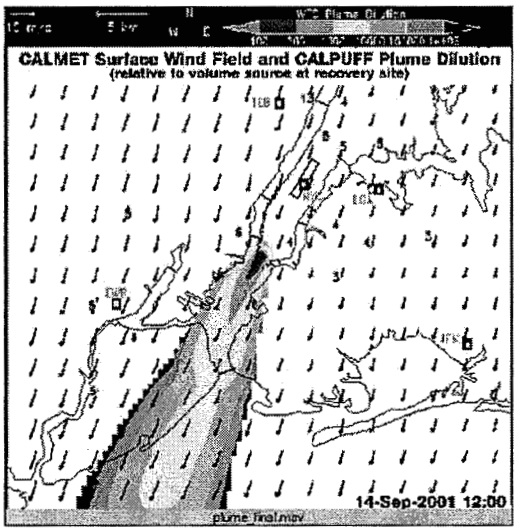


Figure 9. ORD-modeled WTC plume dispersion on September 14, 2001 at 12 noon, indicative of plume flow mainly out over New York Harbor.

Figure 10. Satellite photograph of WTC plume lofting from GZ at 11:54 a.m. EDT on Sept. 15, 2001, and dispersing to the S/SW out over the New York Harbor. (Source: Mandatory credit: "spaceimaging.com".)

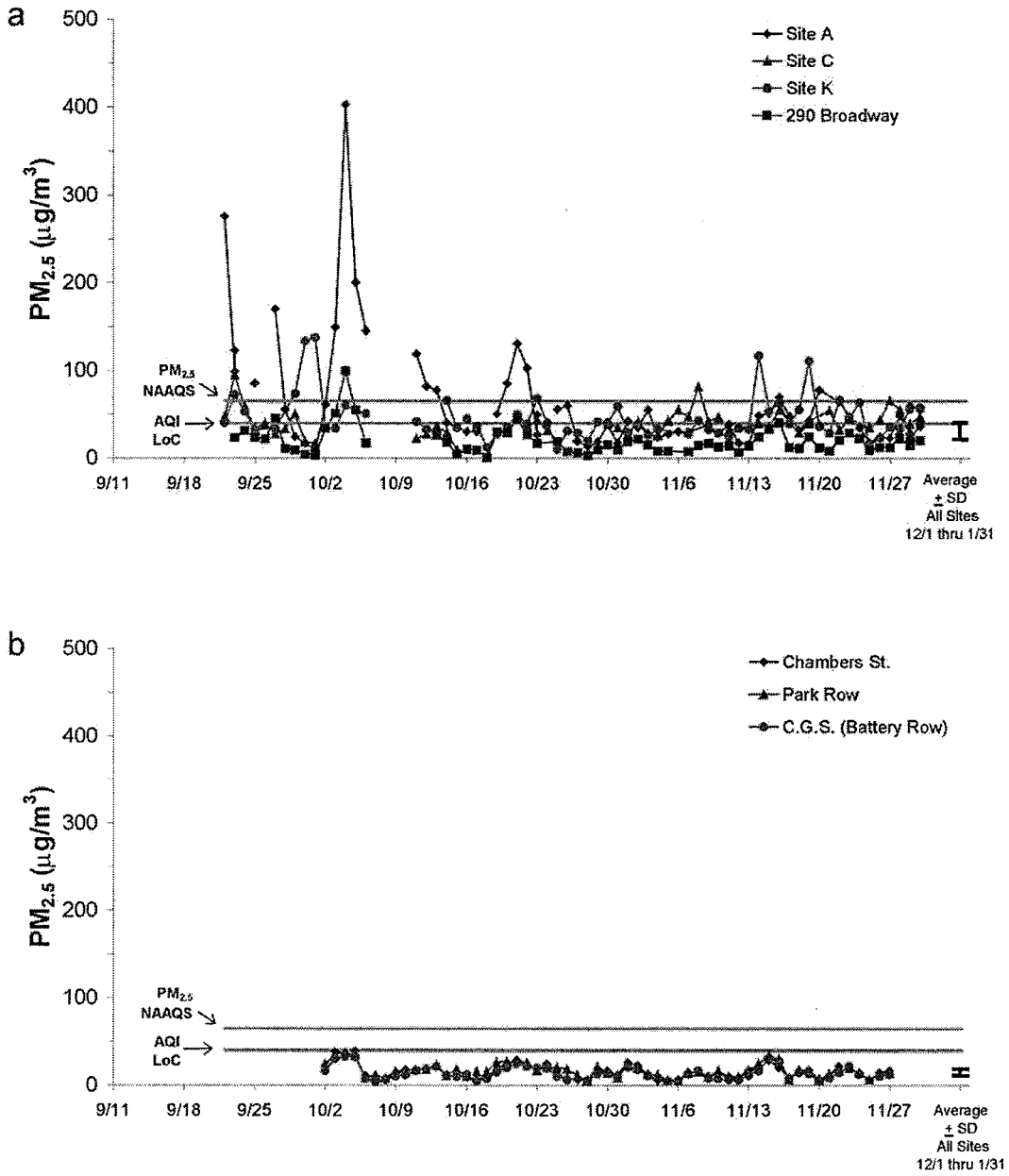


Figure 11. *Panel A (top)*: Daily $PM_{2.5}$ concentrations monitored by EPA/ORD at sites A, C, and K around Ground Zero perimeter and at 290 Broadway 6 blocks northeast of Ground Zero. *Panel B (bottom):* $PM_{2.5}$ concentrations observed at several extended monitoring network sites in lower Manhattan within 3 to 10 blocks of WTC Ground Zero.

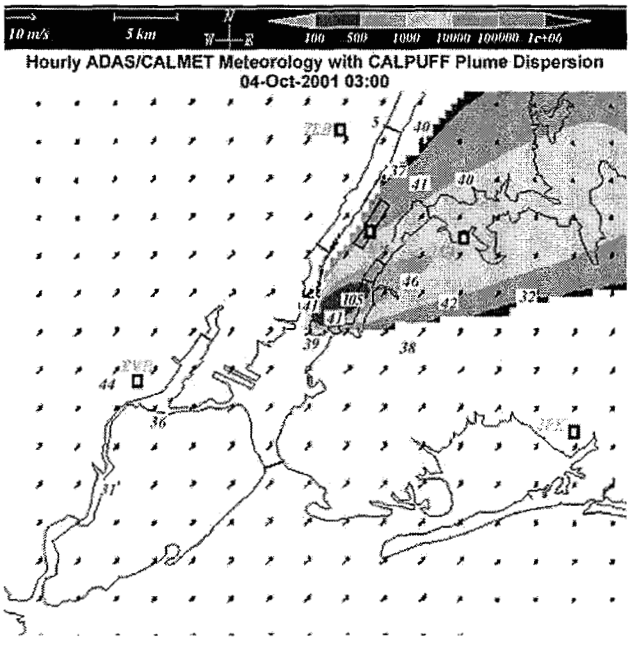


Figure 12. ORD-modeled WTC plume dispersion on October 4, 2001 at 3:00-4:00 a.m. Note the general regional elevation of hourly $PM_{2.5}$ levels (in $\mu g/m^3$) indicated by red numerals for monitoring sites scattered across both northern New Jersey and NYC areas, even outside modeled areas of likely greatest plume intensity indicated by red shading.

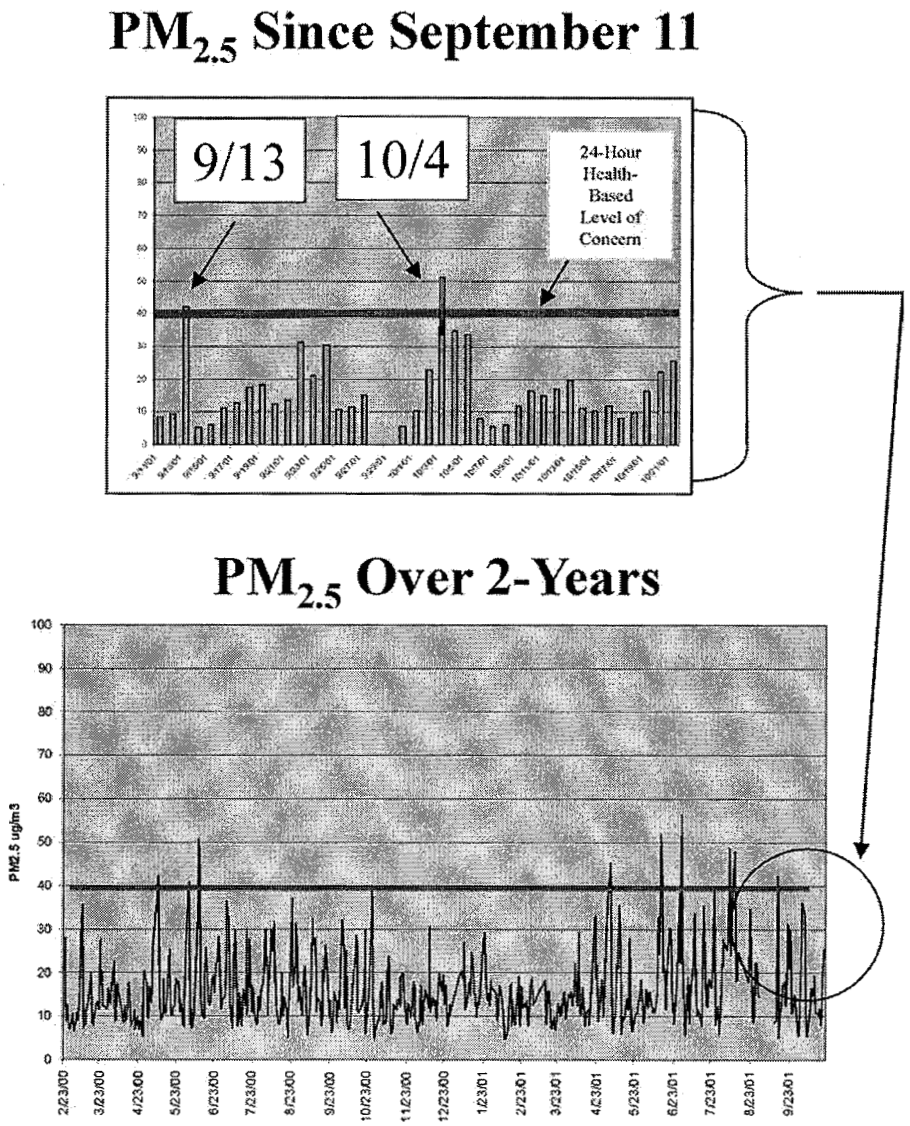


Figure 13. Daily $PM_{2.5}$ concentrations recorded at NYSDEC PS 64 monitoring site after September 11, 2001 (9/11/01 to 10/27/01) compared to historic record of 24-hr $PM_{2.5}$ values at the same site during prior 2 years (2/23/00 to 9/01/01). Note exceedence of 40 $\mu g/m^3$ AQI Level of Concern on September 13 and likely again on October 4; red portion of bar indicates 24-hr average if three high hourly values (> 100 $\mu g/m^3$) being evaluated for data quality are included in 24-hr average calculation.

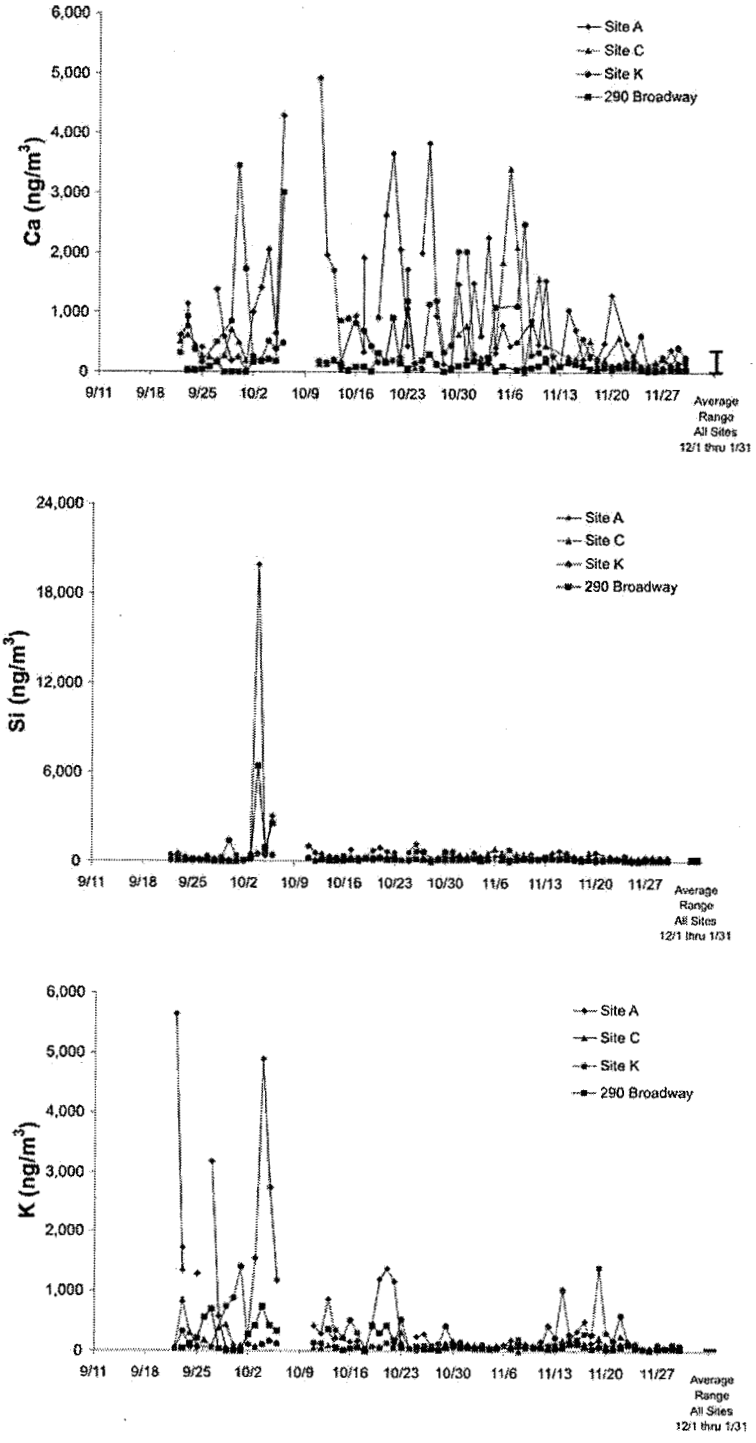


Figure 14. ORD measurement of $PM_{2.5}$ elemental constituents Ca, Si, and K at Ground Zero perimeter sites and 290 Broadway site.

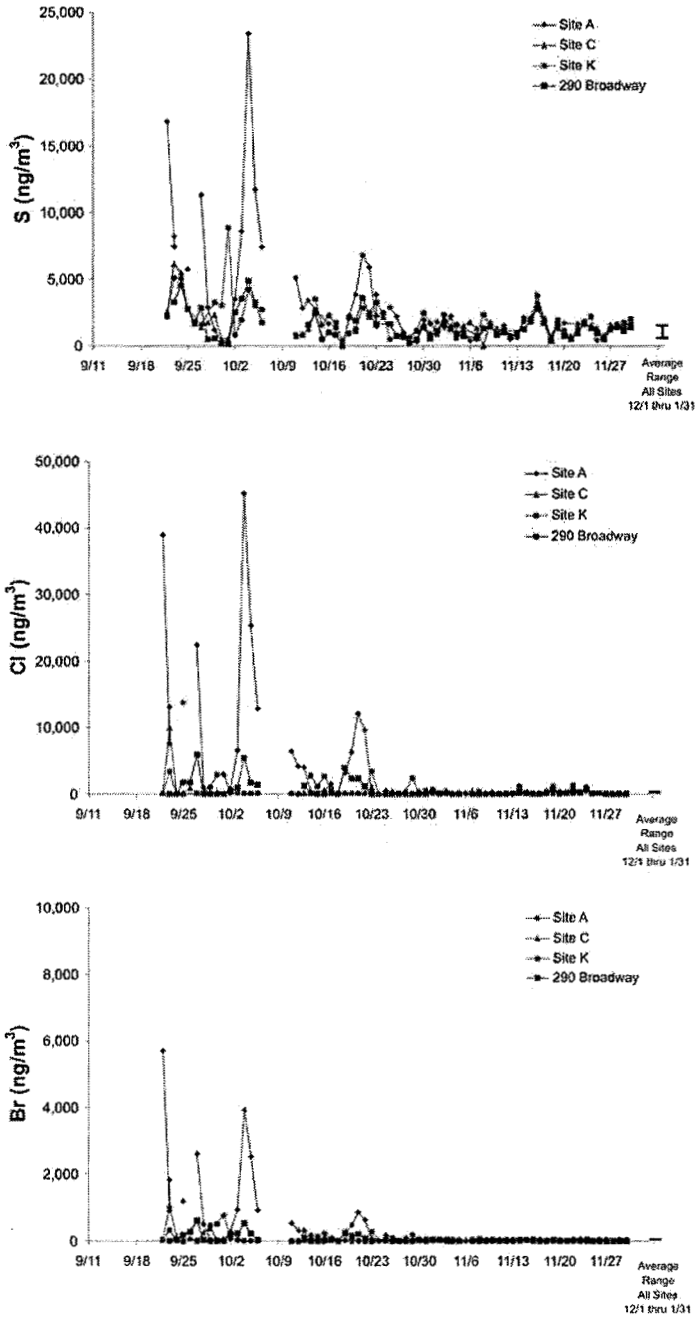


Figure 15. ORD measurements of $PM_{2.5}$ elemental composition for S, Cl, and Br at Ground Zero perimeter sites and 290 Broadway site.

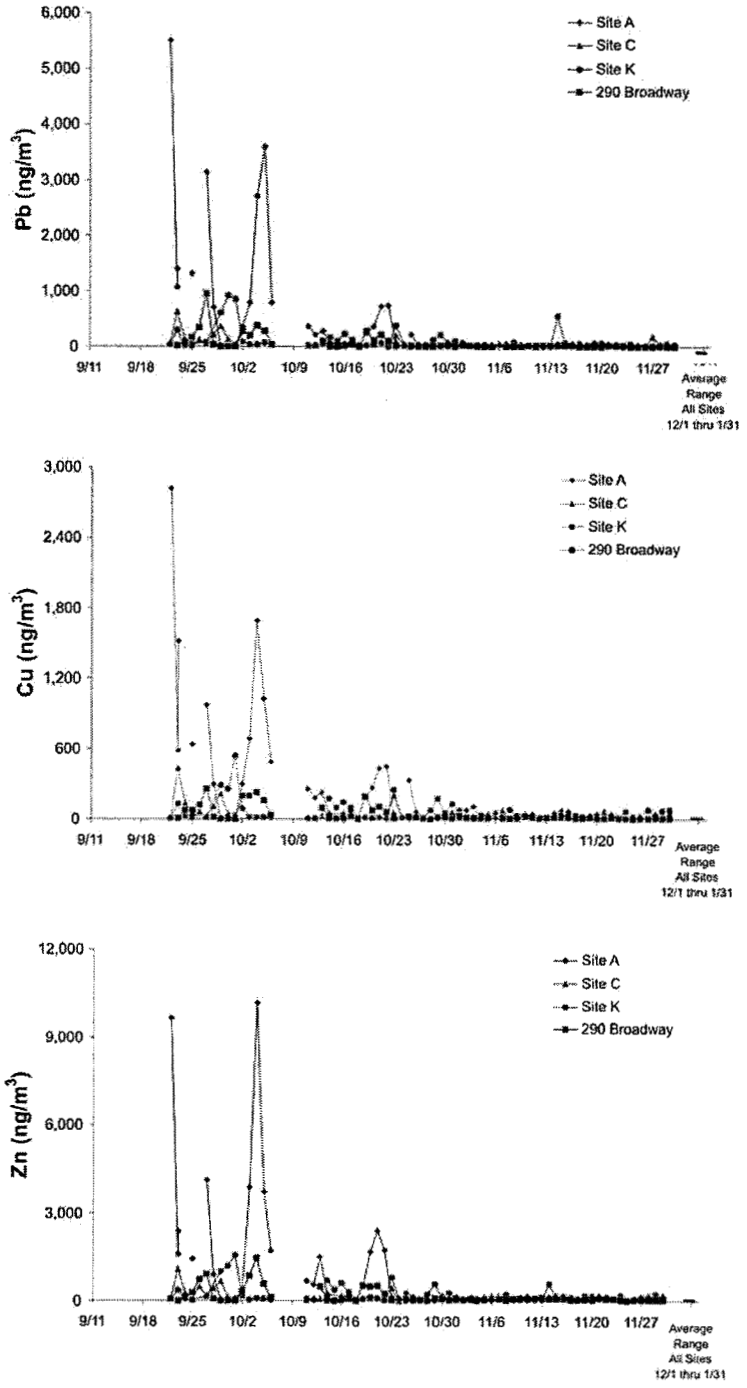


Figure 16. ORD measurements of $PM_{2.5}$ elemental constituents Pb, Cu, and Zn at Ground Zero perimeter sites and 290 Broadway site.

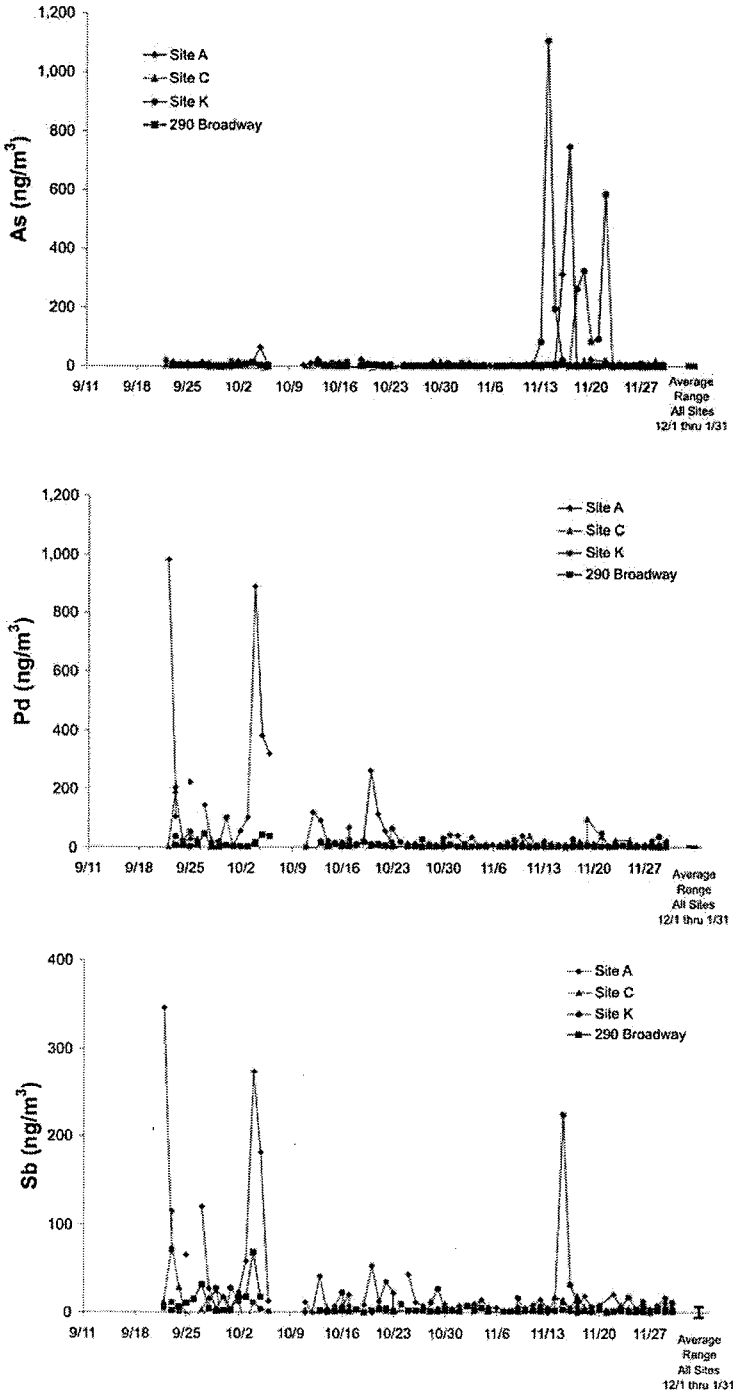


Figure 17. ORD measurements of $PM_{2.5}$ elemental constituents As, Pd, and Sb at Ground Zero perimeter sites and 290 Broadway site.

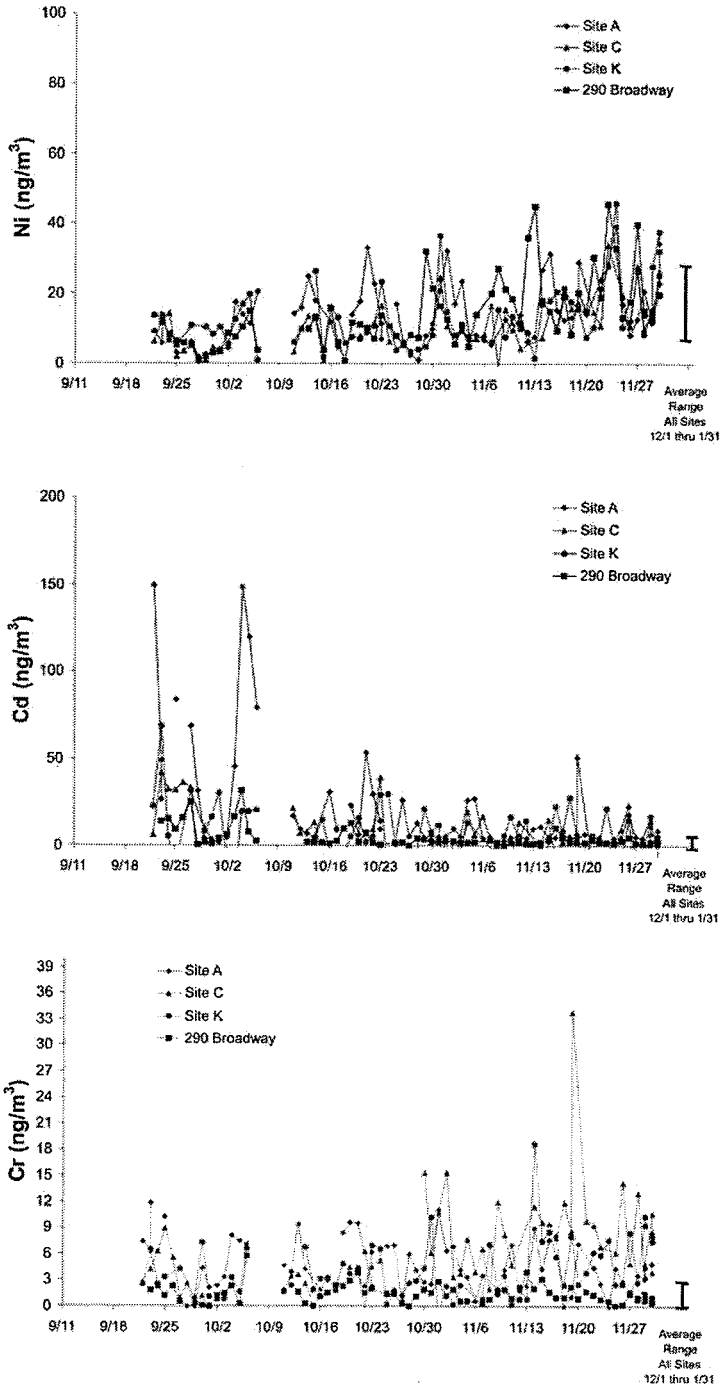


Figure 18. ORD measurements of $PM_{2.5}$ elemental constituents Ni, Cd, and Cr at Ground Zero perimeter sites and 290 Broadway site.

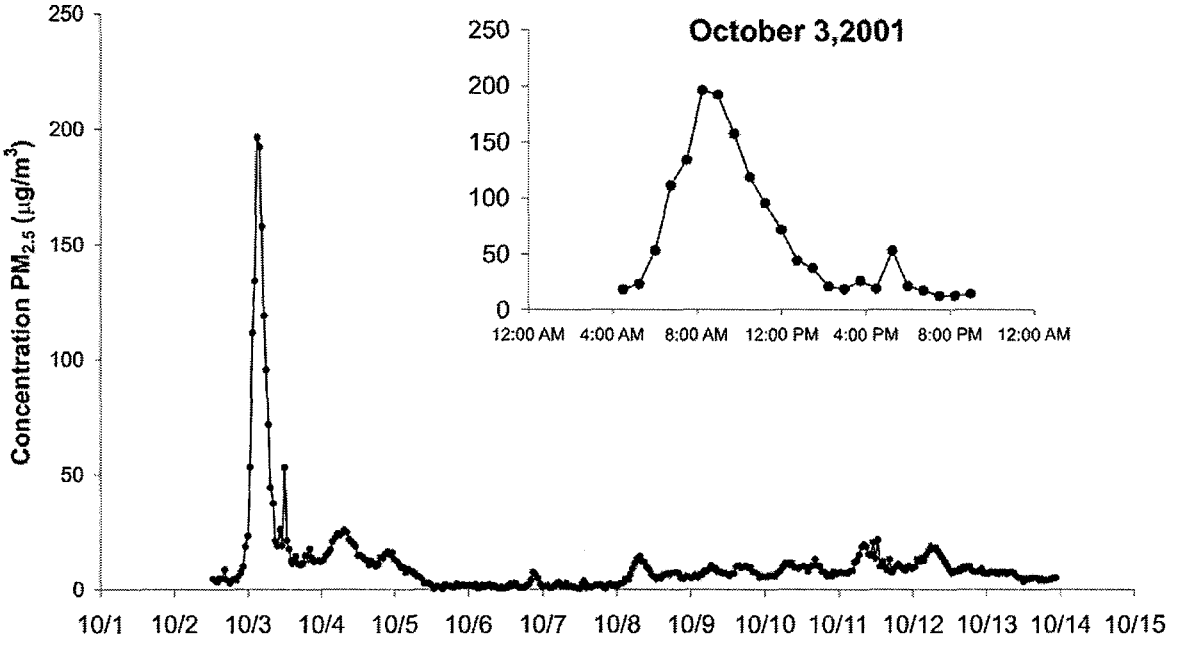


Figure 19. $PM_{2.5}$ concentrations recorded on rooftop of DOE Facility at Varick St., approximately 2.0 miles N/NE of Ground Zero. Note single very high $PM_{2.5}$ excursion mainly restricted to morning hours of October 3 (see inset figure for October 3), consistent with ORD measurements at Location A on the WTC north perimeter and ORD WTC plume plot shown in Figure 12 for October 3.

IV.b. Metals

IV.b.1. Lead

Lead, a silver-grayish soft metal with a relatively low melting point, was still widely used in the 1960s and 1970s (when the WTC was built) in paint and for soldering indoor plumbing joints and electrical wiring systems. It was also used for soldering of computer circuit boards and wiring in a variety of electrical appliances. These uses make it likely that lead would be among the toxic substances of concern at the WTC site. Lead could have been emitted as a combustion product of the ensuing fires or could have been present in reentrained particles stirred up into the air in the course of recovery activities and transport of debris away from the WTC site.

The potential public health concern due to lead exposure most relevant for consideration in relation to the WTC situation is lead intoxication associated with prolonged low-level lead exposures. As discussed in EPA (1986b), such exposure can result in subtle, often subclinical, health effects such as altered calcium metabolism and bone formation/loss, slowed physical growth, and slowed nervous system development of the fetus. Effects on the fetus may be due to exposure of the mother during pregnancy, therefore, women of childbearing age have been identified as an important susceptible population. Other effects of lead intoxication may be slower postnatal growth and neurobehavorial development, IQ decrements and learning deficits, and other neuropsychological effects among young infants and children (another susceptible group).

In 1978, the EPA NAAQS for lead was set at 1.5 $\mu g/m^3$ (90-day average). This level was set to reduce the risk of occurrence of lead intoxication impacts associated with prolonged low-level exposures of susceptible groups. With the EPA phase-down of lead as an additive in gasoline during the past several decades and the current widespread use of unleaded gasoline in the U.S., ambient air lead concentrations have decreased dramatically. Before the start of the phase-down of lead in gasoline in the late 1970s, air lead levels as high as 2.0 $\mu g/m^3$ or more were often detected in U.S. urban areas such as NYC. Currently, 24-hour ambient air lead levels below 0.5 $\mu g/m^3$ are typical of NYC and other U.S. urban areas. NYSDEC Annual Air Quality Reports, for example, indicate (a) arithmetic mean annual-average 24-hour airborne lead levels during 1994 - 1998 of 0.04 to 0.08 $\mu g/m^3$ for a Manhattan (Madison Ave.) curbside sampling site (maximum daily value = 0.34 $\mu g/m^3$) and (b) arithmetic mean annual-average values ranging from 0.02 to 0.09 $\mu g/m^3$ for three Brooklyn/Staten Island sites (maximum daily value = 0.63 $\mu g/m^3$) during 1992 - 1997.

Before the start of gasoline lead phase-out, lead concentrations in outdoor dust were reported (in studies assessed in EPA, 1986b) to range from 280 to 1500 $\mu g/g$ (ppm) in residential areas of NYC and Philadelphia and from 900 to 13,000 $\mu g/g$ in street dust or near heavily traveled roadways in several northern U.S. urban areas (NYC; Philadelphia; Washington, DC; Chicago; Detroit). Despite significant decreases in air lead concentrations, soil and street dust lead concentrations in excess of 500 - 1000 $\mu g/g$ were still observed into the early 1990s in U.S. urban areas (e.g., Boston, Baltimore, and Cincinnati, as described in EPA, 1996). This may reflect, in part, the residuum from earlier gasoline lead deposition from air or more current contamination from deterioration of lead-based paint from residential or other structures or from

industrial production or waste disposal activities.

The potential for very high short-term lead exposures existed during the initial spread of the dust/smoke cloud from the initial WTC collapse; and the ensuing fires, recovery operations, and debris removal may have also posed some lead exposure risks. Examination of air lead data from ORD WTC perimeter sites (Figure 16) and for additional lower Manhattan sites (Figure 20) reveals that 24-hour lead concentrations within (e.g., at WTC Building 5 SW) or at the WTC Ground Zero perimeter (e.g., at Location A, Barclay and W. Broadway; Location B, Church and Dey) approached or exceeded 1.5 $\mu g/m^3$ on several days in late September/early October (e.g., September 17, 23, 27 and October 4, 5). There appeared, however, to be rapid fallout (deposition) of the lead from air close to the WTC rather than the lead being transported over longer distances. This interpretation is based on the relatively uniform low air lead values (mostly less than 0.5 $\mu g/m^3$) seen at the EPA ORD 290 Broadway monitoring site (Figure 16) and at several other locations within a few blocks of the WTC (Figure 20). Consistent with the pattern seen in Figure 16 for EPA/ORD WTC perimeter and 290 Broadway monitoring sites, lead elevations at other lower Manhattan sites outside the WTC work zone generally returned to more typical low background concentrations by mid-October. After October 8, none of the air lead concentrations shown by the WTC Trends Report (EPA, 2002a) for any of the lower Manhattan monitoring sites outside WTC Ground Zero approached or exceeded 1.5 $\mu g/m^3$; in fact, with very few exceptions, nearly all were below 0.5 $\mu g/m^3$. Thus, prolonged lead concentrations averaged over 90 days during late September to late November, 2001, at WTC perimeter or other nearby lower Manhattan sites did not exceed the EPA Lead NAAQS (i.e., 1.5 $\mu g/m^3$, 90-day average). The overall pattern of data, coupled with restrictions of vehicular or pedestrian traffic in lower Manhattan areas close to Ground Zero until very late September/early October, make it doubtful that persons outside the Ground Zero area were exposed sufficiently to airborne lead levels so as to experience any chronic health risks.

There may, however, exist some basis for potential concern with regard to short-term (hours, days) highly elevated lead exposures of individuals working within the Ground Zero perimeter without appropriate respiratory protection. The highest 24-hour lead level shown in Figure 20 was 5.4 $\mu g/m^3$ at WTC Building 5 on September 24. It is likely that comparable or higher elevations in ambient air may have occurred within Ground Zero on some days preceding the start of EPA monitoring in late September. This possibility and the above-noted data showing air lead values approaching or exceeding 1.5 $\mu g/m^3$ on certain days during late September and into October at sites within the WTC work zone or at perimeter sites very close to Ground Zero (within 100 - 200 m) suggest that flare-ups of Ground Zero fires or lead emissions associated with recovery and debris removal operations might have posed risks for individuals within the WTC Ground Zero perimeter. The potential risks would probably be of most concern for pregnant women or other women of childbearing age if any were working within Ground Zero without wearing appropriate protective respirators for extended periods during the first 2 to 4 weeks after September 11. OSHA data (http://osha.gov/nyc-disaster/map.html) do indicate that high air lead levels were detected on September 22 (69.3 $\mu g/m^3$, averaged over 4.5 hr) and September 23 (18.1 $\mu g/m^3$, averaged over 3 hr) by area monitoring near WTC Building 5 well within the Ground Zero work zone. However, none of the OSHA personal sampling data reported for WTC recovery workers (e..g, ironworker, torch-cutter/burner) exceeded the OSHA Lead PEL (50 $\mu g/m^3$, 8-hr average) during late